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International Air Quality Advisory Board. Special Report on Transboundary Air Quality Issues

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International Joint Commission

Canada and United States

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EXECUTIVE SUMMARY

With the approach of the twenty-first century, the International Air Quality Advisory Board (IAQAB) of the International Joint Commission (IJC) undertook a review of the many issues affecting transboundary air quality along the Canada–United States boundary. As an output of that review, this report reflects on several of the issues previously addressed by the Board in its reporting to the Commission and lays out a path for future Board activities.

Since its establishment in 1966, the Board has provided 24 Progress Reports to the Commission on significant transboundary air quality issues. It has also provided other documents on several specialized subjects, including emissions from municipal waste incineration, integrated monitoring, air quality in the Detroit–Windsor region, and estimates of persistent toxic deposition to the Great Lakes. This report draws together many of these same issues: the transport, deposition, and impacts of sulfur dioxide, nitrogen oxides, ozone and particulate matter, as well as selected persistent toxic substances. It also considers, within a regional context along the boundary where appropriate, related issues regarding binational management, monitoring, modeling, surveillance, harmonization of standard-setting processes, collaboration with other organizations, persistent toxic reduction strategies, and anticipatory concerns about coal-fired utilities, mobile sources, and energy conservation.

In this report, the Board emphasizes again that atmospheric pollutants recognize no border or boundary. It therefore recommends that, to effectively manage atmospheric pollutants (such as ozone), both Canada and the United States must take a similar approach, namely the formation of Transboundary Air Pollution Transport Regions (TAPTRs) spanning the boundary region, and the generation of comparable air quality data through continued monitoring and measurement activities.

Since its establishment in 1966, the Board has provided 24 Progress Reports to the Commission on significant transboundary air quality issues. It has also provided other documents on several specialized subjects, including emissions from municipal waste incineration, integrated monitoring, air quality in the Detroit–Windsor region, and estimates of persistent toxic deposition to the Great Lakes.

In this report, the Board also briefly reviews common pollutants — sulfur dioxide, nitrogen oxides, particulate matter, and ozone — and the various receptors on which they have an impact. It presents a rationale for nitrogen oxides as the focal criteria pollutant for the next decade. In doing so, it examines the role of nitrogen oxides in acid deposition, regional haze, and the formation of ozone and fine particulate matter; the absence of substantial emission reductions to date and the likelihood of increased emissions in the future; and the dominance of its principal sources, associated primarily with the generation of electricity and transportation.

The Board next outlines the nature of long-range transport of persistent toxic substances, their deposition and resuspension in the atmosphere, and the scientific needs that must be met if significant sources and source regions are to be identified and controlled. These needs include further research on the physical-chemical properties of these substances and the grasshopper effect; continued monitoring; further development of emission inventories; and modeling to more precisely link sources and receptors on a regional, continental and, in some cases, global basis.

The Board also considers the issue of monitoring and modeling, and, based on data from the Lake Michigan Mass Balance and other studies, emphasizes the need to:

- further extend monitoring of persistent toxic substances downwind of urban areas;
- improve emission inventories for all pollutants;
- develop comparable measurement capabilities amongst agencies in both countries involved in such work; and
- extend the monitoring effort for fine particulate in both countries, within the transboundary region and beyond.

The Board then reviews several crucial air quality issues in five regions along the Canada–United States boundary: Arctic–Far North, Pacific, Mountain–Prairie, Great Lakes–Ontario, and Eastern. In the Arctic–Far North, the Board suggests that the focus should remain on monitoring bioaccumulation and the effects of persistent toxic substances in native populations. Priorities for the Pacific region are programs to further reduce ozone in the Georgia Basin and enhanced monitoring of ozone and other common pollutants on both sides of the boundary area. In the Mountain–Prairie region, continued and extended scrutiny of the ecosystem effects of sulfate deposition and monitoring of these impacts on forests should be emphasized.

In the Great Lakes–Ontario region, in addition to air quality concerns associated with fine particulate and ozone, the focus should be on identifying and quantifying sources of persistent toxic substances, particularly from urban areas, while considering the Great Lakes themselves as sources (via the grasshopper and cold condensation effects). The Eastern (or Atlantic) region would benefit from a further emphasis on monitoring and mass balance, and from continuing development of binational regional strategies for ozone and other pollutants.

In the section on harmonization of standards, the Board revisits its often-stated position in favor of identical standards for common air pollutants in the United States and Canada. Recognizing that this may not occur in the near term, however, the Board advocates binational cooperation in developing a common base of scientific knowledge and formal consultation toward a common interpretation of scientific data for the development of individual standards.

The Board encourages collaboration by the Commission and itself with other organizations, including the Commission for Environmental Cooperation and the United Nations Economic Commission for Europe, which are also engaged in multilateral air quality surveillance and management issues for many of the same contaminants.

In addressing surveillance issues, the Board also notes the need for continued consideration of fine particulate in the Eastern region and for continuous review of the effects of air pollution on various human health and ecological endpoints. At the same time, it emphasizes the limitations and inadequacies of simple emissions trading to solve local and regional air quality concerns.

The Board looks at a number of anticipatory issues and focuses on emissions from the electrical generation and the mobile source sectors. It notes the recent release of two studies by the U.S. EPA (the *Mercury Study Report to Congress* and the *Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units*) and the active discussion concerning sulfur content in gasoline in both countries. The Board further notes that the U.S. EPA utility study discusses concerns similar to those it has raised regarding mercury emissions from coal-fired electrical utilities in the Board's response to U.S. Federal Energy Regulatory Commission (FERC) consideration of deregulation of electrical utilities.

Recognizing that these sectors will require further controls and preventative steps if air quality is to be improved and maintained, the Board plans to continue to assess these and other documents to determine appropriate objectives. It also emphasizes a preventative approach to limit the releases of selected persistent toxic substances from all sectors into the environment. The Board notes that unless such preventative steps are taken, atmospheric emissions of mercury, for example, are likely to increase.

With regard to the sulfur content of gasoline, the Board has advocated, and the Commission recommended to the governments, the establishment of a standard of 30 ppm annual average, with a maximum of 80 ppm, for sulfur content in gasoline throughout both countries, preferably by the year 2001 and no later than 2005.

Finally, the Board offers a summary of its current activities under the Great Lakes Water Quality Agreement priorities for 1997-1999 on persistent toxic substances as well as its other initiatives — tracking sources, transboundary movement, deposition and effects of acid gases (particularly nitrogen oxides), ozone, and particulate matter.

This special report and the issues contained herein identify a number of the major transboundary air pollution issues for the next decade. The Board will continue to track these issues and elaborate on them, with the focus of its work being rooted in the transboundary air quality studies identified in the Commission's October 1997 report to the governments, "The IJC and the 21st Century."

CONSOLIDATED RECOMMENDATIONS

1. SEAMLESS BORDER

Recognizing the need to manage the transboundary region in as seamless a manner as possible, the Board recommends the following:

- The Commission propose to governments that the Canada–United States border region (extending far enough on either side to capture transport distances for at least the common air pollutants) be segmented into Transboundary Air Pollution Transport Regions (TAPTRs) as a focus of further joint effort by the governments. The Board commits itself to provide continual advice and guidance to the Commission as the governments consider this approach and attempt its implementation.

- Within each of the TAPTRs, the Commission should advocate the generation of common harmonized data sets, including emission inventories and monitoring data. Monitoring networks and methodologies and transport models should be continually examined to determine the comparability of their outputs. These data resources should be used to develop truly borderless air quality representations for the transboundary regions.

- For pollutants transported over great distances, such as mercury and POPs (Persistent Organic Pollutants), the Board should continue to identify source regions that contribute significantly to Canada–United States transboundary pollution and review the effectiveness of the governments' control programs in reducing emissions in these regions. This will support a broader continental effort led by the Commission for Economic Cooperation (CEC) in North America. Source regions of these PTSs may in some instances be subsets of the TAPTRs or may be located beyond the boundaries of the TAPTR border zone.

2. NITROGEN OXIDES — THE PIVOTAL POLLUTANT?

While many complex factors influence their production, it is likely that NO_x emissions will change substantially in eastern North America. Given this, the Board recommends the following:

- Current monitoring of NO_x emissions, ambient air concentrations, and deposition should continue. At the same time, further monitoring and process research should be carried out to better understand transformation mechanisms leading to ozone and particulate formation, as well as deposition of nitrogen species in acid rain and as excess nutrient loadings. In addition, resources should be devoted to further research and monitoring of sensitive endpoints affected by NO_x.

- Caution should be used in implementing programs that would result in seasonal control of NO_x as a response to ozone formation which occurs principally in the summer. Such a strategy would not address the formation of other nitrogen pollutants that are believed to have year-round adverse effects on the environment and human health.

3. CONTINENTAL ISSUES — PERSISTENT TOXIC SUBSTANCES

The Board recommends that the Commission closely track implementation of the Great Lakes Binational Toxics Strategy at regular intervals and review the progress in completing specific elements of the strategy as identified by the Board.

4. MONITORING and MODELING

Based on the its review of monitoring and modeling activities for both common pollutants and PTSs, the Board recommends the following:

- The United States and Canada should address and eliminate gaps in available data on levels of fine particulate matter and ozone in the transboundary region through a coordinated binational strategy for monitoring within the region.

- Both countries should collaborate in developing a number of sites where co-located instrumentation can be operated to assure that data generated by each country can be directly compared. The Detroit–Windsor transboundary region should be the location of one such site for monitoring $PM_{2.5}$.

- Both countries should work together to place Canadian and U.S. chemical and meteorological modules on the Models-3 system/platform so that modelers from both countries can compare and develop the best modeling tool to address air pollution issues.

- Both countries should expand routine monitoring capabilities for trace quantities of substances, such as those measured by the IADN, to include measurements immediately downwind of urban areas.

- Both countries should develop comparable and compatible high-quality and publicly accessible binational emissions inventories. These inventories would have a variety of uses, including abatement planning, policy development and implementation, modeling analyses, and public education.

5. REGIONAL ISSUES

The Board recommends that any regional control strategies to limit transboundary air pollution be based on source transport and receptor regions as defined by the pollutant, meteorology and contributing sources.

6. HARMONIZATION AND STANDARD SETTING PROCESSES

While the merit and possibility of harmonized standards continues to be considered by both governments, the Board recommends that, in addition to establishing the TAPTRs, the Commission advocate appropriate inclusion of experts from both countries in the development of air quality standards and criteria by each country, including joint involvement in elements (e.g. monitoring and emission inventory development) that contribute to such processes.

7. COLLABORATION WITH OTHER ORGANIZATIONS

The Board recommends that the Commission maintain a dialogue with the CEC and consider opportunities for interaction with the UNECE to ensure that their work reflects North American practices and to consider which European approaches to determining and managing air quality might be applicable in North America.

8. SURVEILLANCE ISSUES

In conjunction with efforts to assess the release and transport of $PM_{2.5}$, the Commission should ensure that any monitoring network established by the United States over the next five years is at least compatible with, or can be compared to, $PM_{2.5}$ monitoring done in Canada.

The Commission should urge governments to determine appropriate endpoints and indicators of air quality (such as hospital admissions and alterations in fisheries) and to conduct periodic surveys of air pollution receptors (such as sensitive vegetative species) to determine the effects of cleaner air in the border region. This indicator monitoring should include a research component to ensure that all the significant health and ecosystem linkages (e.g. air quality effects on forests) are determined and understood.

9. EMERGING AND ANTICIPATORY ISSUES

The Board has recommended to the Commission the development of a uniform standard throughout both countries for sulfur content in gasoline of 30 ppm annual average, with a maximum level of 80 ppm, optimally by the year 2001 but certainly no later than 2005. Subsequently, the Commission made largely the same recommendation to the governments of the United States and Canada.

INTRODUCTION

While the involvement of the International Joint Commission (IJC) in air quality issues can be traced back to the Trail Smelter issue of the mid 1930s, the International Air Quality Advisory Board (IAQAB) was created in 1966 to provide advice to the Commission in fulfilling an air quality alerting function requested by governments in that year. The current membership of the Board is listed at the end of this report.

This report is separated into ten major sections that consider a number of issues, some of which require immediate deliberation and possible action by the Commission. Other issues are more long-term in nature but will also likely require deliberation and possible action by the Commission.

The major theme revisited by the Board in Section 1 is the need for both the United States and Canada to view transboundary air issues — including current and future concerns regarding fine particulate matter, ozone, persistent toxic substances, visibility and acid rain — under a "one atmosphere" or "seamless border" approach. Eliminating boundaries is crucial in any attempt to identify and understand the sources, transport, and transformation of pollutants that affect the health and welfare of people and ecosystems on either side of the border. Under a seamless border approach to transboundary pollution, both countries can address sources and receptors in a holistic manner, which should allow them to apply the most efficient control strategies and which should result in significant air quality improvement to the benefit of human health and ecosystems.

A seamless border approach would also assist the countries and their agencies in examining issues where localized, regional or multi-regional benefits can result from reduction of the concentrations and/or emissions of specific types of pollutants. The Board has cited several examples of this in past reports and will do so in this report.

This report is separated into ten major sections that consider a number of issues, some of which require immediate deliberation and possible action by the Commission. Other issues are more long-term in nature but will also likely require deliberation and possible action by the Commission.

The three subsequent sections are outgrowths of the seamless border concept. Section 2 discusses NO_X as a key contaminant because of its direct impact on the ecosystem and because it affects future levels of other secondary pollutants. Section 3 outlines the deficiencies of emission inventories regarding persistent toxic substances (e.g. mercury), which must be addressed if source-to-receptor relationships are to be established. Section 4, Monitoring and Modeling, outlines the need to develop these tools to further examine pollutant transport and concentration, and the resulting human and ecological exposure.

Section 5 describes issues in the individual regions along the boundary. Section 6 is directed at the harmonization of standards, which would assist in the effective control of transboundary pollutants such as ozone.

Section 7, Collaboration with Other Organizations, discusses issues important to the IJC and a range of entities examining conditions in the transboundary airshed. Section 8, Surveillance, discusses various feedback mechanisms for verifying that the elimination or management of air pollution is achieving improvement and benefits for the United States and Canada. Section 9 considers emissions and preventative strategies for major source sectors, including coal-fired utilities and mobile sources.

Two additional issues have been cited frequently in both the popular and scientific literature during the past decade: climate change and stratospheric ozone depletion. Although both issues could affect the quality of life and the general well-being of people in the transboundary region, ultimate response action is beyond the sole control of either the United States or Canada. While both nations will undoubtedly continue to interact with the world community to debate both issues and to seek responsive actions, the Board will limit its vigilance of these issues to discussing their linkage with issues open to greater regional control. Reporting bodies, such as the Intergovernmental Panel on Climate Change, should be relied upon to provide thorough coverage of these issues.

1. SEAMLESS BORDER

1.1 One Atmosphere

A wide range of pollutants is released into the atmosphere throughout North America on a daily basis. In the past few decades, both Canada and the United States have made a significant effort to characterize emissions and quantify the relative amounts of pollutants emitted by natural and anthropogenic sources. Anthropogenic emissions change continuously with time, particularly in their chemical composition and their amounts. The pollutants emitted into the atmosphere are transported by wind from source to receptors. In the course of their travel, these pollutants can react in the atmosphere to create other pollutants. Some, such as sulfur dioxide (SO_2), have short average residence times in the atmosphere and may react quickly; others, such as chlorofluorocarbons (CFCs) and persistent organic pollutants (POPs), may exist for years and be transported long distances.

Since the mid 1970's, the study of air pollution issues and the establishment of controls have been based on either one or a small family of pollutants. For example, the primary pollutant considered under the acid rain issue was SO_2, and controls were put in place to control only SO_2. It has recently been shown, however, that nitrogen emissions continue to contribute to acid rain and should be addressed. This emphasizes the need to look at the total picture. The atmosphere can be seen as the one common element; that is, there is only one atmosphere, and most of the pollutants of concern are transported in that atmosphere and/or undergo chemical transformations there.

Since the mid 1970's, the study of air pollution issues and the establishment of controls have been based on either one or a small family of pollutants. For example, the primary pollutant considered under the acid rain issue was SO_2, and controls were put in place to control only SO_2. It has recently been shown, however, that nitrogen emissions continue to contribute to acid rain and should be addressed. This emphasizes the need to look at the total picture.

Figure 1-1 is one depiction of the myriad of processes occurring in the atmosphere. Some contaminants are to a great extent manmade; others, such as mercury can be released by human activity ('manmade') or directly from deposits in the earth's crust ('natural'). Considering mercury further, some portion is released from both sources into the atmosphere where it can be subjected to transport (in some instances over long distances) as well as, in some cases, transformation into derivative compounds. Some contaminants are contained within particles and participate in the processes affecting them. Clouds can capture (scavenge) some portion of these pollutants, with the resulting deposition back to earth in the form of rainfall. Others continually return via dry deposition.

After either form of deposition, pollutants may return to the atmosphere from the site of their deposition (which may be some distance from the original source) in gaseous form (volatilization) or in the resuspension of particles. This cycle of deposition and re-entry to the atmosphere (the grasshopper effect) can be repeated. The effect of these various mechanisms can be transport of the pollutant hundreds or even thousands of kilometers prior to its sustained return to earth.

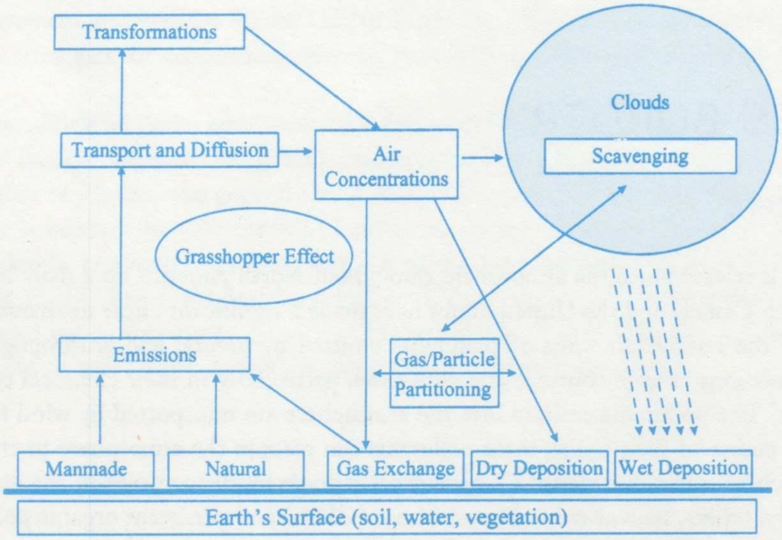

Figure 1-1. Atmospheric Processes

Stachan W. M. J. and Eisenreich S. J. (1988): Mass balance of Toxic Chemicals in the Great Lakes: The Role of Atmospheric Deposition. International Joint Commission, Windsor, Ontario, Canada

Identifying and understanding these processes will give a better understanding of what occurs to all the pollutants found in the atmosphere. This in turn should prompt efforts to address issues more comprehensively and effectively. Rather than addressing issues such as acid rain, smog, fine particulate matter, or toxics singularly, which can lead to additional unforeseen difficulties and negative outcomes, issues should be addressed simultaneously and consistently in a holistic fashion — the same way the atmosphere integrates what is released into it.

1.2 Regional Airshed Management

A variety of regional air quality management frameworks for managing air pollution is being considered in the United States and Canada. Some are designed to deal with a single issue, such as ground-level ozone (O_3) or acid rain, or even a single pollutant, such as SO_2. Others are evolving as regional multi-pollutant, multi-issue management regimes, which may become the frameworks used for managing air quality in the future. In addition, both countries are trying to determine how to better coordinate and apply these evolving regional frameworks in, and perhaps across, border regions.

It is important to distinguish between emission source regions and receptor regions, where effects occur. Because air pollutants are transported in the atmosphere, their adverse effects can occur not only within the emission source regions but also in other regions downwind of the primary contributing sources. For some air issues, such as persistent toxic substances (PTSs), the primary source regions and the primary receptor regions of concern may not be at all coincident; they may, in fact, be quite distant from each other. The pollutants can be controlled, however, only where they are emitted. Therefore, it may be more effective to address these issues by emission source region instead of by the more traditional "airshed" management approach.

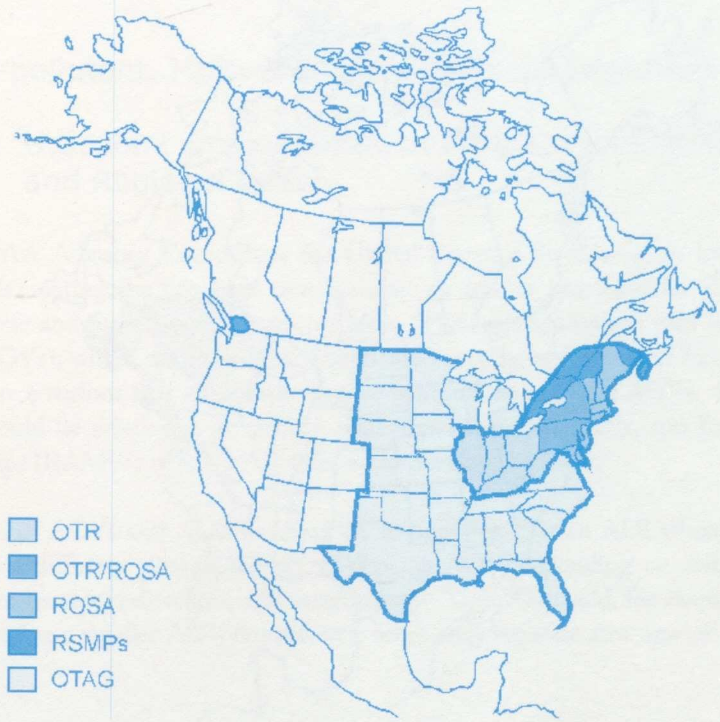

Figure 1-2. **Source Regions — Emission Management Areas for Smog**
Prepared by IJC with input from Environment Canada and U.S. EPA

The following examples will give a better understanding of the evolving air management frameworks.

1.3 Single Issue Management Regimes

1.3.1 Management of Ground-Level Ozone

Figure 1-2 shows the five geographic regimes in place or being considered for managing ground-level ozone in Eastern North America:

- the Ozone Transport Region (OTR), an ozone management region formally designated under the U.S. Clean Air Act (CAA) and covering 13 states in the northeastern United States;

- the Ozone Transport Assessment Group (OTAG) region, covering 37 states in the eastern half of the United States, in which ozone control options are being considered for the region as a whole and for sub-regions within the OTAG domain;

- the Regional Ozone Study Area (ROSA), a region including eight states and an area in southern Ontario jointly designated by the United States and Canada as a logical and scientifically defensible geographic domain for managing ozone in a transboundary context; and

- the Regional Smog Management Plan (RSMP) areas in southern Ontario, southern Quebec, and the southern Atlantic areas of central and eastern Canada. (There is a fourth RSMP in the Lower Fraser Valley of British Columbia).

Many of these geographic regimes are described in further detail in subsequent sections of this report.

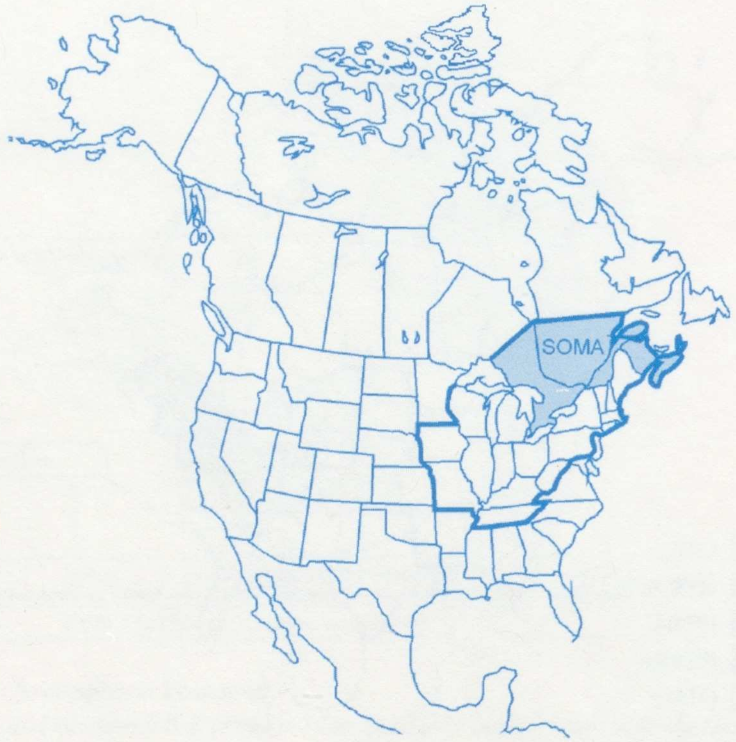

Figure 1-3. **Source Regions — Emission Management Areas for Acid Rain**
Prepared by IJC with input from Environment Canada and U.S. EPA

1.3.2 Management of Acidifying Emissions

Figure 1-3 shows the Sulfur Oxides Management Area (SOMA) formally designated by Canada in the Second Sulfur Protocol under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (LRTAP).

Whereas the management regime for the first phase of Canada's acid rain program of 1985 encompassed the entire territory of the seven easternmost provinces, the second phase now under development is focusing on the SOMA, which is the primary Canadian source region contributing to the residual acidification problem. Acidification is expected to continue in Eastern Canada into the year 2010, even after full implementation of the Canadian Phase 1 control program and the Acid Rain Program under Title IV of the U.S. Clean Air Act.

Prior to the Canadian signing of the UNECE Second Sulfur Protocol, the SOMA was also recognized by the United States as the only area of Canada contributing to acidification in the United States. Hence it is a logical source region for managing SO_2 emissions, both from the domestic and transboundary perspectives. It is also being considered in Canada as an appropriate geographic domain for managing both NO_X emissions, which contribute to acidification and ozone formation, and ammonia emissions, which contribute to ambient air particulate loadings.

As illustrated by the outer boundary in Figure 1-3, the SOMA region might, if fully extended to the transboundary context for addressing acid rain and particulates, be combined with the SO_2 source region in the United States, which modeling has shown to be the primary U.S. source region contributing to the acid deposition region of concern in Eastern Canada.

1.4 Multi-pollutant, Multi-effect Management Regimes

1.4.1 U.S. Joint Implementation Program for Ozone, Particulates, and Regional Haze

Through the CAA Advisory Committee, the United States is developing an integrated regional approach for implementing the proposed new ambient air quality standards for fine particulate matter ($PM_{2.5}$) and ozone and for addressing regional haze. The implementation plan would delineate Areas of Violation (AOVs), which are areas with degraded air quality, and Areas of Influence (AOIs), which are emission source regions that contribute most to contamination in the AOVs. Regionally Integrated Plans (RIPs) would be developed to manage emissions within the AOIs, and Regional Air Management Partnerships (RAMPs) would be established to develop the RIPs.

The designation of AOVs and AOIs is based on recognizing that an AOI where controls are needed may have quite a different geographic extent than an AOV, depending on distribution of emission sources, pollutant transport distances, and meteorology. The AOI could, for example, be either a larger region encompassing a smaller AOV domain or a completely separate area upwind of an AOV.

1.4.2 Canadian Regional Smog Management Plans

At present, four multi-pollutant, multi-effect RSMPs are being developed in Canada. These plans will initially address ozone and particulates, but may also provide the framework for addressing other air pollutants such as persistent toxic substances. The four RSMPs cover the following geographic areas:

- the Lower Fraser Valley of B.C.;
- Southern Ontario;
- Southern Quebec; and
- the Southern Atlantic Region (southern parts of Nova Scotia and New Brunswick).

These RSMPs will be augmented by national measures contained in a National Smog Management Plan (NSMP). RSMPs to address regional hot spots, along with a base national program that provides benefits throughout Canada, comprise the framework envisaged for integrated air management in Canada in the future. Additional RSMPs may be developed as required. The current RSMPs may also be expanded to address other issues, such as deterioration in visibility caused by particulates. Particulate contamination is much more widespread than that of ozone, with ambient particulate concentrations just as high in western Canadian cities (Calgary) as they are in cities such as Toronto that are within the current RSMP domains.

Observations

Jurisdictions on both sides of the border are moving toward a more integrated approach to air issues management. Although some single air issue management schemes are still being considered (e.g. OTAG), both countries appear to be moving toward comprehensive multi-pollutant air management programs for selected emission source regions as a way of managing air quality in the future. Although currently focusing on ozone and particulates, such programs could be expanded to include all air pollutants of concern being emitted from a given region, including air toxics and greenhouse gases.

Even with a regionally focused air management program, however, the need remains for a complementary national program to develop and implement those emission reduction measures that are best handled at the national level, particularly those dealing with vehicles, fuels, and consumer products. Both the United States and Canada have such national programs. Ideally, an overall air management framework would combine the national program and those regional programs designed to further reduce emissions in key source regions.

An air management framework with a strong regional focus and a comprehensive multi-pollutant approach offers many advantages over single-pollutant, single-issue programs:

- improved efficiency for both governments and industry;
- more effective selection of emission control measures that address a range of pollutants (e.g. measures to control greenhouse gases could control other air pollutants);
- a single comprehensive package of measures for industry, allowing them to better plan for the future; and
- some assurance of environmental integrity by providing regional based controls.

1.5 Pollutants

1.5.1 Sulfur dioxide (SO_2)

Historically, emissions of SO_2 from uncontrolled coal burning, together with smoke from domestic, industrial and other sources, constituted the earliest recognized air pollutants. In both Canada and the United States between 1980 and 1997, mandated controls on stationary sources have led to substantial reductions in the annual tonnage of SO_2 emissions; further reductions are expected over the next decade. A key to these reductions has been the control of emissions from large smelters and coal-fired electrical generating plants.

From 1980 to 1994, SO_2 emissions in the United States and Canada are estimated to have declined by 6.0 million tonnes (6.6 million tons), or 23%. Over the same period, the seven eastern provinces of Canada lowered emissions from 3.4 million to 1.5 million tonnes (3.8 million to 1.7 million tons), a reduction of more than 55%.

Since sulfates are a major component of acid rain, SO_2 emission reductions were an essential part of the strategy in both countries to reduce the formation of acid species. Controls on the sulfur content of diesel fuel in both countries has also led to a further reduction in SO_2 emissions.

Sulfur dioxide can contribute to adverse effects in both natural vegetation and humans. Natural vegetation is sensitive to SO_2 and to the aerosol (sulfuric acid) to which it is a precursor. The effects on vegetation have been quantified. In addition, it has been known for over a decade that asthmatic subjects are sensitive to SO_2. Protective standards have generally been based on this effect. While the role of SO_2 and sulfates in causing long-term human health effects is less well established, it is now generally agreed that aerosol sulfates, an important component in $PM_{2.5}$ pollution, cannot be ignored in this regard. Monitoring networks for SO_2 are generally satisfactory, and the resources deployed to record changes in acid deposition have provided adequate information to allow long-term trends to be documented.

1.5.2 Nitrogen oxides (NO_X)

This report includes a special discussion of oxides of nitrogen (see Section 2). Oxides of nitrogen include NO (nitric oxide), which is emitted as a consequence of combustion processes such as those associated with vehicles and electrical power generation. Nitric oxide is rapidly oxidized to nitrogen dioxide (NO_2), which is a relatively stable compound. Ambient NO_2 in North America is used as a general indicator of the density of automobile and truck traffic, since in terms of total tonnage, this sector generally dominates the NO_X emission inventory. Standards for NO_2 emissions from vehicles are in place in both Canada and the United States, and have led to substantial reductions in emissions per vehicle over the past twenty years. However, because these progressive reductions have been outweighed by the increased number of vehicles and their increased use in many regions, total NO emissions have not been much affected. In the case of some large stationary sources, several pilot and full-scale projects have demonstrated that significant reductions in NO_X emissions can be achieved through substitution of oxygen for air in the combustion process and through catalytic treatment of stack emissions.

Nitrogen dioxides and hydrocarbons are the main precursors to the formation of tropospheric (i.e. ground-level) ozone. Growing concern over sustained acidification of sensitive ecosystems and the effects of increased ozone levels in many parts of Canada and the United States has led to discussion of the need for additional NO_X emission reductions. Nevertheless, strategies are being developed in many areas to address ozone and other pollutants. As these strategies are implemented, steps to reduce NO_X emissions will likely be taken as well.

1.5.3 Acid Rain

Reductions in SO_2 emissions have been central to lowering the acidity of rain on both sides of the Canada–United States boundary. Recent evidence suggests that, with the advent of sulfur dioxide reduction programs, the nitrate component of acid rain, largely influenced by NO_2, has assumed more importance. Reductions in NO_X emissions have been more difficult to achieve than for SO_2, largely because of the importance of the transportation sector as an emission source. The research conducted since the problem of acid rain was first widely recognized in the early 1970's has led to a much better understanding of its impact on forest species and forest growth and on freshwater resources.

1.5.4 Tropospheric Ozone

Ground-level ozone is formed by a complex series of reactions that occur when NO_X and hydrocarbons co-exist in the presence of sunlight. Ozone formation was first recognized in Los Angeles in 1952. The problem was initially thought to be confined to that region, but for the past twenty years it has been recognized as a significant concern in every part of the world. Ozone, as well as its precursors, exists long enough in the atmosphere to allow major transboundary transfers to occur: it is thought to be capable of traveling as far as 750 km (460 miles) from the major source of its precursors.

Ozone is an intense oxidizing agent. It is capable of causing inflammation in the human lung when breathed at concentrations as low as 0.08 parts per million (ppm). Epidemiological studies have shown that emergency room visits and admissions for acute respiratory disease in all age groups are associated with ozone levels at concentrations currently experienced in many portions of the U.S. and Canada. Field studies of children at summer camps have demonstrated that ambient ozone levels cause a measurable decline in lung function. Similar effects have been found in fruit pickers in the Fraser Valley working ten-hour days in atmospheres of less than 0.08 ppm of ozone. Several studies have also found that ozone levels are associated with increased daily mortality.

Many crops are sensitive to ozone exposure during the growing season, and the economic impact of ozone at current levels in some regions is thought to be considerable. Native forest species are also sensitive to ozone, although there has been some difficulty in distinguishing which effects on natural forests are ascribable to ozone and which to acid species.

It is now recognized that a reduction in the emissions of both hydrocarbons and NO_X is necessary to limit ozone formation. In some regions, natural hydrocarbons from trees are believed to be responsible for as much as 30 per cent of the ozone formed. In completely urban regions, hydrocarbons are largely derived from gasoline fugitive emissions and certain chemical processes. In Los Angeles and the northeastern United States, requirements for vapor recovery technology have been imposed to limit hydrocarbon emissions when automobiles are refueled. The NO_2 contributions to ozone formation are primarily the result of anthropogenic emissions from stationary and mobile sources.

1.5.5 Particulate Pollution and Haze

Particulate pollution originates from windblown dust, smoke, and direct emissions of particles from mobile and stationary sources. It also originates from the formation of secondary aerosols, particularly organics, nitrates and sulfates, from reactions of contaminants such hydrocarbons, NO_X and SO_2 emitted to the atmosphere. Although all particles less than 10 microns in diameter (PM_{10}) are respirable into the human lung and therefore potentially capable of causing adverse effects, it has recently been recognized that particles less than 2.5 microns in diameter ($PM_{2.5}$) may constitute the fraction most responsible for demonstrated adverse health effects. Because $PM_{2.5}$ is capable of traveling long distances, transboundary atmospheric transport is inevitable.

There is now a large body of epidemiological data indicating that daily mortality, particularly from respiratory and cardiac causes, is associated with PM_{10} and $PM_{2.5}$ levels. These studies have now been reported from 30 different regions on three continents with very different climatic conditions and with differing associated pollutants. Other indicators of significant adverse health effects are the diminished lung function of children, hospital admissions for respiratory disease (both acute and chronic), aggravation of asthma, and possibly the risk of lung cancer.

The detailed biological mechanisms of these very diverse effects and the components of $PM_{2.5}$ responsible for them are not yet fully understood. There is some indirect evidence that particles from diesel engines may be more toxic than others and that particles from the earth's crust are less toxic. Until the nature of the toxic particles is more precisely known, however, it is generally considered appropriate to treat all PM_{10} and $PM_{2.5}$ particles, regardless of their origin, as potentially harmful.

Regional haze is associated with fine particulate matter ($PM_{2.5}$ or smaller). Depending on their origin in North America, these particles can be dominated by secondary sulfates, nitrates, carbon, or soil-related materials. Visibility-reducing particles may come from large combustion sources, vehicle emissions, forest fires, road dust, mining operations, or residential wood burning. On both sides of the border, regional haze is monitored according to protocols established by the Interagency Monitoring of Protected Visual Environments (IMPROVE) network developed by the U.S. National Park Service. The United States has 69 IMPROVE or IMPROVE 'protocol' sites in many of the 156 Class 1 protected (parks and wilderness) areas. The number of IMPROVE sites will increase to 108 should pending national regional haze rules receive Congressional approval.

In July 1997, the U.S. Environmental Protection Agency (EPA) proposed regional haze rules that would use deciviews as the standard visual index for the 156 protected areas. The deciview reflects perceived visual changes: a one-deciview change represents a change in scenic quality that would be noticed by most people.

In the United States under the pending legislation, state implementation plans (SIPs) would be required to control particles causing regional haze in order to attain the national visibility goal of no impairment in designated areas. As haze is often formed in areas some distance from the source of the original pollution, the Board encourages the formation of regional partnership groups to deal with downwind emissions that reduce visibility in another state.

1.6 Receptors

Along the Canada–United States border, regional pollutants of concern (ozone, PM, $PM_{2.5}$, and acid rain) are currently affecting sensitive receptors. These receptors include both natural resources and human populations, especially sensitive groups such as asthmatics, children and the elderly. Visibility, the ability to see scenic vistas, is also subject to being degraded in parks, wilderness areas, and refuges. In controlling regional pollutants, streams, lakes, fisheries, grassland, alpine and forested ecosystems, and wildlife would also benefit. An emerging natural resource issue is the effect of nitrogen inputs to estuaries and coastal ecosystems, where eutrophication can result in oxygen depletion and other negative effects on fisheries and water quality. These sensitive receptors are found in all regions along the border, without reference to political boundaries.

Recommendations

Recognizing the need to manage the transboundary region in as seamless a manner as possible, the Board recommends the following:

- The Commission propose to governments that the Canada–United States border region (extending far enough on either side to capture transport distances for at least the common air pollutants) be segmented into Transboundary Air Pollution Transport Regions (TAPTRs) as a focus of further joint effort by the governments. The Board commits itself to provide continual advice and guidance to the Commission as the governments consider this approach and attempt its implementation.

- Within each of the TAPTRs, the Commission should advocate the generation of common harmonized data sets, including emission inventories and monitoring data. Monitoring networks and methodologies and transport models should be continually examined to determine the comparability of their outputs. These data resources should be used to develop truly borderless air quality representations for the transboundary regions.

- For pollutants transported over great distances, such as mercury and POPs (Persistent Organic Pollutants), the Board should continue to identify source regions that contribute significantly to Canada–United States transboundary pollution and review the effectiveness of the governments' control programs in reducing emissions in these regions. These actions will support a broader continental effort led by the Commission for Economic Cooperation (CEC) in North America. Source regions of these PTSs may in some instances be subsets of the TAPTRs or may be located beyond the boundaries of the TAPTR border zone.

2. NITROGEN OXIDES - THE PIVOTAL POLLUTANT?

In considering the recent history of air quality assessment and air pollution management, the Board suggests that nitrogen oxides are currently the most significant of the common pollutants.

Nitrogen oxides are a collection of gaseous nitrogen species that play a major role in atmospheric chemistry and that can significantly affect ecosystems and human health. The predominant source of NO_X is the combustion of fossil fuel to produce thermal, electrical, and mechanical energy. NO_X is most often emitted as NO, sometimes accompanied by smaller amounts of NO_2. It contributes to the formation of photochemical oxidants (i.e. ozone) that cause adverse effects in humans, plants and materials. Nitrogen species are also implicated in global warming and stratospheric ozone depletion (i.e. formation of the "ozone hole").

In air, NO_X is converted to nitric acid and particulate nitrate, which then contribute to precipitation acidity and $PM_{2.5}$, and negatively affect visibility and human health. Acid precipitation and deposition of nitrogen species have resulted in episodic acidification of fresh waters, fish kills in eastern North America, eutrophication of estuaries, soil-water acidification in forests, and changes in soil microbes.

2.1 Health Effects

It has proven difficult to establish with certainty the existence of adverse human health effects solely attributable to ambient NO_2. Animal studies give evidence that NO_2 interferes with lung defenses, which may explain the considerable amount of data indicating that, at current high levels, NO_2 exposure (both indoors and outdoors) increases the incidence of respiratory infections in children. One episode in London, England, in December 1991, when NO_2 reached 400 parts per billion (ppb) for eight consecutive hours on two consecutive days, did cause increases in the values of some health indicators, but there was no explosive increase in asthma attacks. It was not possible to clearly distinguish the effects of the rise in NO_2 level from the concomitant rise in particulate matter in this case.

The predominant source of NO_x is the combustion of fossil fuel to produce thermal, electrical, and mechanical energy. NO_x is most often emitted as NO, sometimes accompanied by smaller amounts of NO_2. It contributes to the formation of photochemical oxidants (i.e. ozone) that cause adverse effects in humans, plants and materials.

Studies on human subjects have shown that pre-exposure to low levels of NO_2 increases the response to subsequent exposure to low levels of ozone — a phenomenon that may be of significance in real-life situations. However, a great deal is not yet known about the patterns of human exposure to NO_2: it is difficult to make inferences from differing annual exposure levels, and the close correlation between NO_2 and PM_{10} in many environments also complicates epidemiological studies attempting to isolate the effects of NO_2.

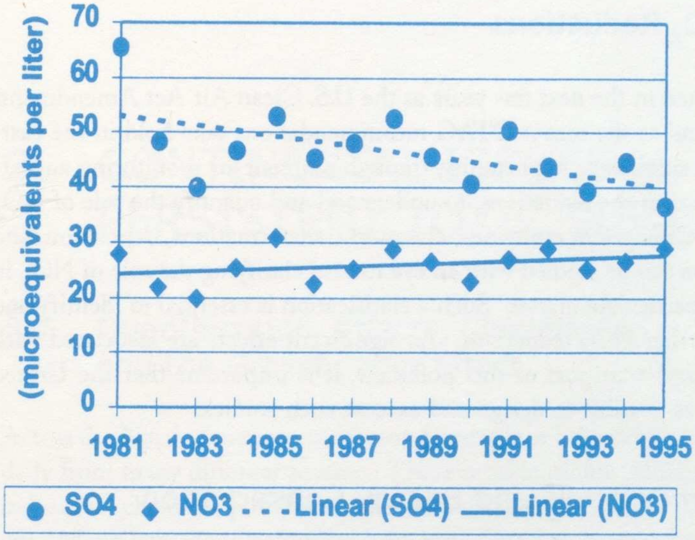

Figure 2-1. Sulfate and Nitrate Trends in Bennington, VT Precipitation.
Trends in Precipitation Chemistry in the United States, 1983-94; An Analysis of the Effects in 1995 of Phase 1 of the Clean Air Act Amendments of 1990, Title IV. APC Division, Vermont Agency of Natural Resources, August 1997.

2.2 The Importance of Monitoring

Since NO_X is a collection of compounds that can be transformed into such secondary species as nitric acid, ammonium nitrate, and organic nitrogen, it is important to understand the speciation distribution of nitrogen compounds in both emissions and secondary air pollutants. Such an understanding, which is essential for determining how NO_X affects the environment and human health, requires routine and continuous chemical monitoring of emissions, ambient air, and deposition. Without this, the role of NO_X in the atmosphere and ecosystem cannot be completely and quantitatively understood. Currently, our knowledge of NO_X releases from pollution sources is based on a vehicle emission inventory, which is believed to be comprehensive, and on emission inventories for stationary, area, and fugitive sources, which are comparatively incomplete.

2.3 Emission and Deposition Trends

Recent trends in nitrogen speciation and deposition can be derived from wet deposition data of the U.S. National Atmospheric Deposition Program (NADP). Trends in emissions in the United States indicate that NO_X emissions appear to have remained level over the past decade, while sulfur oxide (SO_X) emissions have been substantially reduced.

In some areas, however, data indicate that wet nitrate deposition has increased, while sulfate deposition has decreased. For example, NADP precipitation chemistry data, which track the fate and transport of pollutants from local and upwind sources, show transfers of air contaminants to sensitive Vermont aquatic and terrestrial ecosystems. Figure 2-1 shows nitrate and sulfate concentrations in rain and snow in Bennington, Vermont, from 1981 to 1995. Nitrate concentrations appear to have increased, while sulfate concentrations have decreased. This decline in sulfate deposition is believed to be a consequence of SO_X reductions from power plants in the eastern United States, where further reductions are anticipated as Title IV of the U.S. CAA continues to be implemented. The increase in nitrate deposition is believed to be due to the lack of concurrent efforts to reduce NO_X emissions from vehicles and power plants.

2.4 Anticipated Future NO_x Reductions

NO_x emission reductions can be expected in the next few years as the U.S. Clean Air Act Amendments of 1990 continue to be implemented and as the recent OTAG recommendations take hold in the eastern United States. This will provide a significant opportunity, through ambient air monitoring and atmospheric research before, during, and after the reductions, to understand and quantify the role of NO_x in the atmosphere and in ecosystems. Changes in emissions, chemical transformations, deposition, and environmental and human health effects can be studied with an eye toward clarifying the role of NO_x in the formation of ozone, acid rain, and particulate matter. Such a clarification is essential to identify and understand the probable impacts of further NO_x reductions. As significant effects are associated with the long-range (including transboundary) transport of this pollutant, it is important that the United States and Canada collaborate as soon as possible to design and execute such studies.

2.5 Technology: Emission Controls and Energy Conservation

NO_x emissions can be reduced by retrofitting sources with control technology and by adopting energy conservation measures. Proven NO_x control technology, although expensive, is now available and in use. Energy conservation measures have played a major role in restraining the growth rate of NO_x emissions, but emissions have nonetheless continued to increase in many areas. Because of the link between energy use and air pollution, it is clear that additional energy conservation steps — with a particular emphasis on vehicular efficiency — are needed. Over the long term, these steps will need to include widespread use of low- and zero-emission vehicles (LEVs and ZEVs), development of alternative fuels and energy sources, and further advances in energy conservation in the industrial and residential sectors. These steps — which may be taken as part of efforts to reduce carbon dioxide (CO_2) releases in response to concerns about anticipated global climate change — will provide a significant additional benefit in the form of reduced NO_x emissions.

"End of pipe" emission control policies, while imperative in the short term, will be inadequate to achieve widespread reductions of NO_x and other emissions in the long term. As the twenty-first century begins, technologies that are highly energy efficient and designed around the philosophy of "zero discharge" must be developed. While this philosophy should be applied to all sectors and activities, particular emphasis should be placed on decreasing the intensity of energy use and increasing the energy efficiency of both fossil fuel-fired, thermal-electric generating plants and the transportation sector.

Recommendations

While many complex factors influence their production, it is likely that NO_x emissions will change substantially in eastern North America. Given this, the Board recommends the following:

- Current monitoring of NO_x emissions, ambient air concentrations, and deposition should continue. At the same time, further monitoring and process research should be carried out to better understand transformation mechanisms leading to ozone and particulate formation, as well as deposition of nitrogen species in acid rain and as excess nutrient loadings. In addition, resources should be devoted to the further research and monitoring of sensitive endpoints affected by NO_x.
- Caution should be used in implementing programs that would result in seasonal control of NO_x as a response to ozone formation which occurs principally in the summer. Such a strategy would not address the formation of other nitrogen pollutants that are believed to have year-round adverse effects on the environment and human health.

3. CONTINENTAL ISSUES: PERSISTENT TOXIC SUBSTANCES

3.1 Quantification, Effects, Challenges, and the Grasshopper Effect

Across the North American continent, hundreds of hazardous pollutants are emitted into the atmosphere daily from many different sources. These include motor vehicles, oil and gas combustion, metallurgical industries, chemical production and manufacturing, gasoline production and distribution, and solvent use. Many hazardous pollutants have been found as contaminants in surface water, sediment, drinking water, and food. The air pathway and atmospheric deposition have increasingly been identified as factors in these occurences. Most of the pollutants only contribute to local problems and are not transported long distances. One subset of these hazardous pollutants, however, is a group known as persistent toxic substances. PTSs tend to volatilize and move through the atmosphere, frequently crossing boundaries before they are deposited. Hence, they have become a cause for continental and global concern.

Because PTSs tend to undergo biomagnification and bioaccumulation, their impact is greatest on animals at the top of the food web: predatory birds, fish, and mammals, including humans. Exposure to PTSs seldom results in acute symptoms or death, but it can impair reproductive capabilities and reduce resistance to disease. Studies of the chronic effects of exposure, however, are very difficult to conduct. For example, epidemiological studies are often impeded by the long latency period (decades in some cases) from the time of exposure until the onset of effects.

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Once PTSs have been emitted into the atmosphere, their ultimate destination depends in part on their chemical and physical characteristics and in part on prevailing meteorological conditions. Most PTSs remain in the atmosphere for several hours to a few days — long enough to cross into neighboring states, provinces, or countries. In addition, because some of these compounds are semi-volatile, they can evaporate and become airborne early in the day, and condense and deposit onto soil, vegetation or water later in the day. Some also show a similar seasonal cycle. This process of recycling through the atmosphere is known as the "grasshopper effect." Although there are considerable uncertainties that prevent exact quantification of transport, it is generally agreed that the "atmospheric region of influence" is very large.

There is considerable evidence of the long-range transport of PTSs and of their bioaccumulation in animals and humans in different parts of North America, including remote areas of the Arctic where no local sources exist. There are, however, major uncertainties regarding the source regions and magnitude of PTS emissions, and the rate of transport through the atmosphere. Although quantities in the atmosphere are often below detection, there is evidence that they nevertheless contribute significantly to bioaccumulation in fish, birds, and mammals.

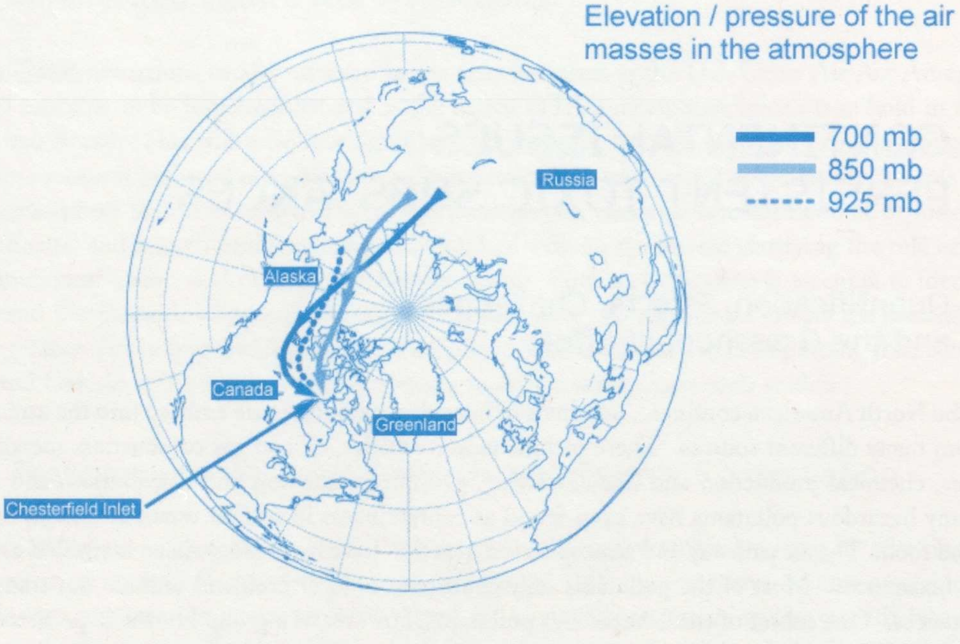

Figure 3-1. The "Brown Snow" Event in Chesterfield Inlet, 27-28 April 1988: 120-Hour Back-trajectory of the Air Mass Containing Fine Particles and POPs.

H.E. Welch, et al. 1992. Brown Snow: A Long-Range Transport Event in the Canadian Arctic. Env. Sci. Tec. 25: 280-286.

Residuals from past uses of these PTSs remain in the environment. Contaminated soils and sediments abound in many areas; leachate and volatiles from landfills often contain these compounds. These are sources that are difficult to identify and quantify with any known accuracy. As an example, for more than a decade now, Lake Ontario has been acting as a net source of polychlorinated biphenyls (PCBs) that are degassing out of the lake at a rate that currently exceeds inputs.

Emissions from sources outside the continent also contribute to the accumulation of PTSs in North America, and vice versa. The transport of PTSs from outside North America to regions such as the Arctic is well documented. Figure 3-1 (Brown Snow), shows the pathway through which particles and persistent organic pollutants from the former Soviet Union are transported to the Arctic. To define the air pollution source–receptor relationship between North America and other continents and regions, however, considerably more data are needed.

The major PTSs and the key issues associated with them are briefly described below.

3.2 PCBs and PICs

PCBs are a group of chemicals that were introduced in 1929 and manufactured in developed countries until the late 1970s. However, some production apparently continues in parts of the former Soviet Union. Because PCBs are chemically stable and heat resistant, they were used worldwide as electrical transformer and capacitor oils, hydraulic and heat exchange fluids, lubricating and cutting oils, and plasticizers in joint sealants. While their use is currently banned in all developed countries, substantial amounts of PCBs still remain in large capacitors and transformers.

There is little information about current use and disposal of PCBs. Improper disposal in the past has resulted in a large number of sites that contain PCB-contaminated sediments and soils. These sites are also suspected to be significant sources of atmospheric emissions, although the magnitude and extent of these emissions are not known.

Several "products of incomplete combustion" (PICs) — including polycyclic aromatic hydrocarbons (PAHs) and other polycyclic compounds containing oxygen and nitrogen — are persistent in the environment. The PICs of most concern are dioxins (PCDDs) and furans (PCDFs), a group of chlorinated chemicals that are toxic to life forms in minute quantities. Dioxins and furans can enter the environment in many ways. Waste incinerators that are not equipped with efficient flue-gas cleaning systems are known to be one of the most significant sources. Wood-burning stoves and the burning of leaded automotive fuel also add to loadings in the atmosphere. Dioxins and furans also enter the environment as trace byproducts of industrial processes, including processes used in metallurgical industries. Pulp and paper mills using elemental chlorine in their bleaching process often release water contaminated with dioxins. Traces of these contaminants have also been found in chlorophenoxy acid herbicides (e.g. Agent Orange), in chlorophenol wood preservatives, and in PCB mixtures (mainly furans). Hexachlorobenzene (HCB) is another trace byproduct in the production of chlorine gas and chlorinated compounds, including several pesticides. HCB is also emitted to the atmosphere by waste incineration and metallurgical processes.

Many substances used as flame retardants have chemical properties that are similar to PCBs. Polybrominated diphenyl ethers can leach out of electrical equipment, building materials, car interiors, and textiles treated with flame retardant to contaminate the environment. Knowledge of the toxicity of brominated flame retardants is very limited.

3.3 Pesticides

Many PTSs are pesticides — organic compounds with several chlorine atoms designed to be toxic to their target organisms. Most affect the nervous system and the liver; several interfere with reproduction. Although most industrialized countries have eliminated or restricted the use of first-generation pesticides over the last two decades, much of the developing world still uses them for public health and pest control purposes. Of primary concern are DDT, toxaphene, chlordane, mirex, aldrin, dieldrin, and hexachlorocyclohexanes.

3.4 Metals

Metals occur naturally in the environment as part of the earth's crust. They are emitted into the air and water through both natural and anthropogenic processes. The heavy metals of primary concern are mercury, cadmium, and lead. These three metals can have discernable toxic effects to life forms although their levels in the atmosphere are only moderately above background concentrations.

Mercury also occurs naturally as elemental mercury and in organic and inorganic compounds. Much of the mercury in the environment is strongly bonded to sediment and organic matter, making it unavailable to organisms. Microorganisms, however, can convert inorganic mercury into methyl mercury, a fat-soluble molecule that easily passes through cell membranes, accumulates in animals, and biomagnifies in the food web. The processes controlling methylation and bioaccumulation are poorly understood. Because mercury is a nerve toxin, there are health concerns about its effect on the brain, as well as damage to the reproductive, digestive, and sensory systems. Plants can also be sensitive to mercury, particularly at high concentrations, which can lead to reduced growth.

Two primary anthropogenic sources of mercury are fossil fuel combustion (particularly coal) and waste incineration. Other sources include the chlor-alkali industry and non-ferrous metals production. Mercury is commonly used in thermometers, barometers, dental fillings, batteries, switches and fluorescent lamps, and is thus present in waste containing these items.

Cadmium is toxic to most forms of life. It can be taken up directly from water, and to some extent from air and food, and has a tendency to bioaccumulate in both plants and animals. Kidney damage, decalcification of the skeleton, and emphysema are the serious chronic effects of high cadmium exposure, but these are encountered only in some occupational settings. Cadmium is a byproduct in the pyrometallurgical production of zinc, which is the leading anthropogenic source of cadmium to the environment. Cadmium is also a byproduct in the production of lead. Other major sources include fossil fuel combustion and waste incineration, and the manufacture of alloys, pigments, metal coatings, batteries, and electronics. Cadmium is also a contaminant in chemical fertilizer, manure, compost, and sewage sludge. Cigarette smoking is another major cause of cadmium accumulation in humans.

Lead in the environment is readily absorbed by sediments and soil particles, and is therefore largely unavailable to plants and animals. Leaded gasoline, however, has been and, outside of the United States and Canada, continues to be a major source of lead emissions to the environment on the continental scale. Lead is also emitted from the mining and metallurgic industries, ammunition manufacture and use, and municipal waste incineration. It accumulates in the liver, kidney, spleen, and skeleton; it can damage the nervous and gastrointestinal systems, and interfere with the formation of red blood cells.

Over the past two years, the Board has reviewed current efforts in the United States and Canada to address the issue of PTSs in the environment, including efforts underway to implement the Great Lakes Binational Toxics Strategy signed by both countries in April 1997. The Board has determined that:

- more effort is required to determine the physical and chemical properties of the 29 individual and groups of pollutants identified in the strategy;
- several of these pollutants, including mercury, PCBs and dioxins, persist long enough in the atmosphere to allow them to be transported over large regions, if not globally;
- emission inventories for these contaminants are inadequate and should be improved and made accessible to the research community;
- attempts to model the transport and deposition of these contaminants should be expanded further; and
- linkages between significant sources and transboundary receptor areas should be defined.

Recommendation

The Board recommends that the Commission closely track implementation of the Great Lakes Binational Toxics Strategy at regular intervals and review the progress in completing specific elements of the strategy as identified by the Board.

4. MONITORING and MODELING

As noted in the Introduction, the goal of this report is to review current transboundary air issues using a "one atmosphere" or "seamless border" approach. Because the atmosphere knows no borders and plays a major role in the transport and transformation of pollutants that can affect public health and ecosystems across North America, it is only logical that the United States and Canada attempt to address air pollution issues in this context. The seamless border approach is particularly relevant to the various tools used to examine and understand air issues and policies. Two of these tools are monitoring and modeling.

There have been several bilateral monitoring projects between the United States and Canada, the most notable being the field of acid deposition. From 1981 to 1983, an intercomparison study of Canadian and U.S. wet deposition measurements was carried out by collocating precipitation chemistry samplers at several Canadian and U.S. sites. The results, published by Bigelow (*Environmental Science & Technology*, 1991), clearly pointed out that Canadian measurements were deficient. This led directly to the formation of a new, improved Canadian wet deposition network, the Canadian Air and Precipitation Monitoring Network (CAPMoN). The valuable information gained from the first intercomparison study and the recognition of the need to ensure the compatibility of the two countries' data led both countries to collocate wet deposition instruments at one site in each country (at Pennsylvania State University in Pennsylvania and at Sutton in Quebec). A second study (the results of which are about to be published) demonstrated that both countries' sulfate measurements are highly comparable, although measurement of other species (such as ammonium and hydronium) is not. The information from this study played a part in the NADP/NTN network's decision to change monitoring protocols in 1994.

The seamless border approach is particularly relevant to the various tools used to examine and understand air issues and policies. Two of these tools are monitoring and modeling.

At present, the collocation study has been expanded to further identify why differences between the two countries exist, with a goal of eventually harmonizing the measurements. The study has now collocated the samples of four different networks at the Penn State intercomparison site: CAPMoN, NADP/NTN, AIRMoN, and CASTNet. The results will be described in a multi-agency paper currently under preparation. These intercomparison studies have helped define the uncertainty associated with North American wet deposition maps created by merging U.S. and Canadian wet deposition data.

A similar process has been undertaken in the field of air quality measurements. Of particular note was a comparability study carried out during the U.S.–Canada Eulerian Model Evaluation Field Study (EMEFS), in which two Canadian and two U.S. filter pack sampling networks were intercompared at Penn State. The results, which were published by McNaughton and Vet (*Atmospheric Environment*, 30:2, 1996), showed that the uncertainty of the measurements by the two countries was within 10 per cent for all species measured. The study subsequently led to a long-term U.S.-Canadian intercomparison study of air concentration measurements and dry deposition estimates.

The latter study is taking place at the Centre for Atmospheric Research Experiments in Egbert, Ontario, where both CAPMoN and CASTNet filter pack/dry deposition sampling instruments are collocated. The study results, described in preliminary form in the *1994 Canada–US Air Quality Agreement Progress*

Report, indicate a high level of comparability for sulfate and nitrate measurements, but poorer comparability for SO_2 measurements. A statistical comparison of U.S. and Canadian dry deposition estimates at this site will soon be undertaken to determine the compatibility of the inferential dry deposition models and estimates from the two countries. The close collaboration between U.S. and Canadian scientists in the measurement (and model development) areas is leading to closer harmonization of both.

Another example of comparison studies is the Integrated Atmospheric Deposition Network (IADN), a joint U.S.–Canadian monitoring network that addresses PTSs transported to and deposited in remote areas of the Great Lakes. The IADN is made up of five master stations and several satellite stations on both sides of the Great Lakes. It has provided the necessary standardized methods, monitoring data, and loading estimates to allow first assessments of the relative importance of atmospheric deposition compared with other inputs (e.g. effluents and sediments) within the Great Lakes. The IADN does not specify samples or sampling protocols, as long as comparability among all participants can be established. At each site, concentrations of target chemicals are measured in rain and snow (wet deposition), airborne particles (dry deposition), and airborne organic vapors. Precipitation rate, temperature, relative humidity, wind speed and direction, and solar radiation are also measured. The Quality Control-Quality Assurance program developed as part of the IADN has been used as a model in other efforts to measure toxics in the atmosphere, such as the St. Lawrence Action Plan, the Lake Michigan Mass Balance, and the European Monitoring of the Environment Program (EMEP).

Similar examples of collaborative modeling can be cited. For example, as part of the efforts to address the acid rain issue, an External Review Panel of the EMEFS used data from an extensive field study undertaken during 1988 and 1990 to review two Eulerian models: the U.S. Regional Acid Deposition Model (RADM) and the Canadian Acid Deposition Oxidants Model (ADOM). That review, which was described in a report published in May 1994 (Report of the Fourth Meeting of the External Review Panel, Niagara-on-the-Lake, Ontario Canada), drew the following conclusions:

- The models can be used to evaluate total sulfur deposition on a regional scale, averaged over a month or more.
- The models can be used to evaluate total nitrate deposition on a regional scale averaged over a month or more.
- As of 1994, use of the models to develop emission control strategies for ozone is *not* recommended.
- Models can be further developed for use in visibility analysis. This would require an upgrading of the aerosol description in the models.

Since that comparison, work to improve the models and their associated chemistry modules has continued.

A more recent example of a collaborative modeling effort is the binational North American Research Strategy on Tropospheric Ozone (NARSTO). Presently, a proposal is being put before NARSTO's Executive Committee to intercompare Canadian and U.S. models using field data collected as part of the two recent NARSTO field campaigns. The intent is to work jointly on developing the best modeling techniques to address the North American ozone issue.

The preceding discussion demonstrates the successes to date stemming from the cooperative work of the United States and Canada in the development of both monitoring and modeling to address air issues that recognize no borders. Four current issues remain, however, where such collaborative efforts should be enhanced.

First, in the monitoring area, the U.S. EPA is presently proposing to install 1,500 monitoring sites nationwide for fine particulate ($PM_{2.5}$). Simultaneously, Canada is enhancing monitoring networks to address the fine particulate issue. There is some question, however, as to whether the instrumentation being installed in the two networks will yield comparable data.

Second, in the modeling area, the U.S. EPA is developing a Models-3 project. The project is intended to develop a flexible and general modeling system/platform to support multi-pollutant and multi-scale air quality simulation, while taking advantage of the enhanced computational capabilities provided by high-performance computing and communications systems. The Models-3 project will allow different chemical and meteorological modules to be run simultaneously. The Board believes it is important to ensure that Canadian scientists and modelers are involved in the Models-3 project throughout its development and use.

Third, collaboration between the two countries will be important in conducting additional mass balance studies in waters along the border. The contribution of the various sources of environmental pollutants, particularly PTSs, needs to be better understood in the border regions and beyond. Much has been learned from the application of mass balance models in the Great Lakes and the Gulf of Maine. This type of analysis should now be completed to better understand air pollution impacts in the Pacific, Arctic–Far North and Lake Champlain–St. Lawrence regions.

Finally, the current IADN consists of five regional background measurement stations, one on each of the Great Lakes. Because these five sites avoid urban regions and industrial plumes, the net result is good regional estimates of concentrations of several organic and inorganic contaminants. This approach is flawed, however, in that it does not consider that many of the larger particles are generated and concentrate in more developed areas. Estimates of deposition of some materials to the Great Lakes are thus likely to be low by an undetermined amount. A more complete understanding of the relative importance of atmospheric deposition of pollutants will require deposition measurements in and around urban areas.

Recommendations

Based on the its review of monitoring and modeling activities for both common pollutants and PTSs, the Board recommends the following:

- The United States and Canada should address and eliminate gaps in available data on levels of fine particulate matter and ozone in the transboundary region through a coordinated binational strategy for monitoring within the region.
- Both countries should collaborate in developing a number of sites where co-located instrumentation can be operated to assure that data generated by each country can be directly compared. The Detroit–Windsor transboundary region should be the location of one such site for monitoring $PM_{2.5}$.
- Both countries should work together to place Canadian and U.S. chemical and meteorological modules on the U.S. Models-3 system/platform so that modelers from both countries can compare and develop the best modeling tool to address air pollution issues.
- Both countries should expand routine monitoring capabilities for trace quantities of substances, such as those measured by the IADN, to include measurements immediately downwind of urban areas.
- Both countries should develop comparable and compatible high-quality and publicly accessible binational emissions inventories. These inventories would have a variety of uses, including abatement planning, policy development and implementation, modeling analyses, and public education.

5. REGIONAL ISSUES

5.1 Artifact Regions

For the purposes of this report, the Canada–United States border area has been divided into five regions: Arctic–Far North, Pacific, Mountain–Prairie, Great Lakes–Ontario, and Eastern. For each of these "artifact regions," this chapter describes the status of air quality and atmospheric deposition, identifies sensitive receptors of air pollution, and describes any significant transboundary air management strategies in the states and provinces. It must be noted, however, that these regions do not represent airsheds, which, depending on the pollutant of interest, can extend many kilometres in all directions from the border. The Board notes that the boundaries defined for the purpose of linking sources (both point and area) and receptors in a specific airshed will vary in size and shape, depending on the location of sources and receptors, the extent of transport of the individual pollutant, prevailing meteorology, and contributing source types.

5.2 Arctic–Far North

The Alaska–Yukon and Alaska–British Columbia borders areas are sparsely populated, with virtually no industry. It appears that, although there are localized occasions of poor air quality, there are no major transboundary air pollution concerns in the region. However, some transboundary issues along the Alaskan border were noted in the Commission's 1995 *Comments Received on the Canada–United States Air Quality Agreement — A Report to the Governments of Canada and the United States.* These concerns dealt with smoke from open burning and wildfires, ice fog, and haze.

There is great concern about the long-range air transport of persistent toxic substances from distant sources and their subsequent deposition in the Arctic environment. Northern native populations are particularly susceptible to the effects of toxic substances . . . because these pollutants tend to bioaccumulate to high levels in the tissues of the fish and wildlife on which native populations rely for food.

A number of wide-ranging air pollution issues affects the Arctic as a whole. Arctic haze is air pollution in the form of fine droplets of sulfuric acid, particles of soot, and other contaminants carried north from areas such as Eastern and Western Europe. It is widespread and can be detected in large parts of the Far North during winter and early spring. Potential effects include decreased visibility, acid snow and a possible contribution to climate change.

Persistent toxic substances are usually generated and released from anthropogenic activities such as agriculture and industry, almost exclusively in lower latitudes. There is great concern about the long-range air transport of these substances from distant sources and their subsequent deposition in the Arctic environment. Northern native populations are particularly susceptible to the effects of toxic substances such as PCBs, DDT, and mercury because these pollutants tend to bioaccumulate to high levels in the tissues of the fish and wildlife on which native populations rely for food. These pollutants are not generally released locally. Specific pollution incidents such as the Exxon-Valdez oil spill also create transboundary concerns.

This region is known for its large tracts of protected wilderness. Wrangell-St. Elias National Park and Preserve in Alaska, contiguous with Kluane National Park in the Yukon, is the largest national park complex in North America. Visitors to these and other wildlands along the border have recently found degraded scenic vistas due to visibility-reducing particles, generated principally from wildfires and prescribed forest burns.

There are currently no regional air management strategies in place for this region. Vigilance is needed in the event that resource utilization, such as drilling for oil and gas and mineral extraction in the Arctic National Wildlife Refuge, is contemplated in the future.

5.3 Pacific

The transboundary pollution released from a smelter at Trail, British Columbia, into the adjacent U.S. state of Washington approximately 60 years ago was one of the initial references to the IJC. This smelter is now being rebuilt, and emissions of particulate, SO_2, and lead have declined over the past ten years, with the expectation of further decline on completion of the present work.

Some forest stands of the Cascade Mountains in Washington State are downwind from Vancouver and may be affected by elevated levels of ozone. The transfer of photochemical pollutants in both directions (north and south) is significant.

Aerosol nitrates and ozone formed in the Fraser Valley as a result of emissions from urban Vancouver can have impacts, including decreased visibility, on adjacent areas of the United States. Levels of ozone in the Canadian sector of the Fraser Valley have reached 200 ppb on occasion; more commonly, daily peaks are below 100 ppb. However, health studies of farm workers near Abbotsford picking fruit for ten hours a day have shown that even an ozone peak below 80 ppb has a measurable effect on lung function. It is believed that current ozone levels are affecting the productivity of sensitive crops, such as alfalfa grass, in the Fraser Valley; further control programs will be required to address them. Levels of particulate pollution are generally low in coastal regions. In British Columbia as a whole, higher values for particulate matter are recorded in inland cities such as Prince George than on the coast.

The geography of the Lower Fraser Valley also allows significant transfers across the boundary from south to north. Quantities of SO_2 from refineries in Whatcom County, Washington, and of ammonia from agricultural activities affect pollution levels in the Fraser Valley. There is some indication of low pH precipitation on Saturna Island and Victoria as a result of transport from Puget Sound.

Monitoring networks are in place on both sides of the boundary, as far up as 40 km (25 miles) north in the Fraser Valley, and collaborative consultation between the U.S. regulators in Whatcom County and regional and provincial authorities in British Columbia occurs through regular meetings of a joint council established for this purpose. The adequacy of the monitoring, however, remains a concern. The monitoring network in the Fraser Valley is adequate for regulatory purposes, with a dense and comprehensive monitoring program conducted by the Greater Vancouver Regional District (G.V.R.D.). Beyond the borders of the G.V.R.D., however, there are only three monitoring sites on the Canadian side of the border and one on the U.S. side. This is not adequate to satisfactorily track changes in air quality. Proposals to add regional-level monitoring to Whatcom County are now being formulated. The governments noted that they are also working on the Georgia Basin Ecosystem Initiative, which will assist in characterizing and managing these issues in coming years.

5.4 Mountain–Prairie

This region extends from the Cascade Mountains east to the Rocky Mountains and into the Great Plains region of Canada and the United States, including much of the provinces of Manitoba, Saskatchewan, Alberta, and British Columbia, and the states of North Dakota, Montana, Idaho, and Washington. This region is characterized by low population density but significant resource utilization, including mining, timber harvesting, and energy development. It contains some of the largest intact wilderness areas in North America and is home to many of the large ungulates (hoofed species) and carnivore species (e.g. wolves) that are subject of preservation efforts.

Regional and local sources of particulate and gaseous emissions include wood production operations (e.g. beehive burners, slash burning, pulp and sawmills), wildfires and prescribed burns, resource extraction (e.g. mines, oil and gas drilling and processing, smelters), fertilizer production and use, feedlot operations, agriculture, and fossil fuel combustion (e.g. coal-fired electrical generating facilities). The few large point sources of criteria pollutant emissions include smelters and oil and gas facilities in Alberta, Montana, and North Dakota. Transport of elevated ozone concentrations from the Greater Vancouver and Seattle areas to the mountains has been measured. This transport from urban areas, coupled with possible stratospheric intrusions of ozone, account for elevated ozone concentrations at high elevations. Recent studies of forest fire emissions in Alberta indicate that large burns can contribute to elevated ozone concentrations downwind.

U.S. NADP wetfall monitoring in Washington, Idaho, and western Montana and North Dakota showed the annual average pH in the border states to range from 5.1 to 5.6, levels that are close to "background" values. Deposition of sulfate was in the range of 1 to 3 kilograms per hectare (0.89 to 2.7 pounds per acre), with nitrate and ammonium concentrations being elevated in eastern North Dakota as a result of emissions from agricultural operations and feedlots. A U.S. Rocky Mountain study showed snow deposition of sulfur and nitrogen compounds in the border region to be low when compared with loadings measured in the Front Range in Colorado, downwind of some large coal-fired power plants and the population centers of Denver–Boulder–Fort Collins. Thus, acid precipitation is not currently indicated as a principal issue in this portion of the boundary, but certain localized areas do show cause for concern. In the Cascade Mountains in Washington, snow deposition downwind of the Puget Sound area contains elevated concentrations of sulfur, nitrogen, and trace metals.

Visibility monitoring in parks and preserves shows the impact of both forest fires (wild fires, prescribed burns, and slash burning) and industrial emissions from sources in the border states and provinces. Monitoring at the contiguous preserves of Waterton Lakes National Park in Alberta and Glacier National Park in Montana indicated that two thirds of the particles that reduce visibility in these two parks originate in Canada, and one half of that contribution comes from sources within Alberta. A special visibility study carried out in Kootney National Park in the Canadian Rockies recorded layered haze due to local sources of wood combustion, and uniform, regional haze due to transport of particles from wildfires burning in the western United States. In this region, there are many major national parks and few population centers on both sides of the border, with a number of areas on the U.S. side designated as Class I protected areas under the U.S. CAA. Therefore, concern is focused on effects on natural resources, surface water quality, and preservation of scenic vistas in these large protected areas.

Resource characteristics that might be affected by anthropogenic air pollution include high-elevation lake and stream water quality, forest productivity, grassland soil fertility, and visibility in scenic areas. Both the Rocky Mountains and the Cascade Range contain large numbers of high-elevation lakes and streams, many of which have low buffering capacity. In general, these fresh waters are not currently affected by deposition of acids or sulfur or nitrogen compounds, with the exception of some ultra-low buffered lakes in the Washington Cascades. Many of the forested lands in this region are suffering from drought, insect infestations, and the consequences of poor management through fire suppression, but it is unlikely that air pollution has significantly affected these coniferous forests.

5.5 Great Lakes–Ontario

The Great Lakes constitute the largest body of surface fresh water on earth and one of the planet's most valuable natural resources. The Great Lakes Basin includes the actual Great Lakes and over 760,000 square kilometres (295,000 square miles) of land that drains into them. Home to roughly 36 million people, the Great Lakes Basin is one of North America's major industrial and agricultural regions.

The Great Lakes contain significant levels of hazardous air pollutants, including PTSs, due to both local sources of pollution and long-range atmospheric transport (as illustrated for PCBs in Figure 5-1). Over the past several years, annual average ozone levels in the basin have been consistently higher than the 15 ppb Canadian national annual ambient air quality objective. In general, annual average levels of total suspended particulate (TSP) in Ontario have not declined over the last several years. Sulfate levels in the Basin have declined slightly over the same period.

Studies conducted in the Great Lakes region and elsewhere have provided strong evidence linking air pollutants such as ground-level ozone, airborne particles and acid aerosols to indicators of adverse effects on respiratory health, including decreased lung function in children, increased hospital admission for respiratory diseases, and increased health costs. Figures 5-2 and 5-3 compare ozone levels and sulphate concentrations with hospital admissions.

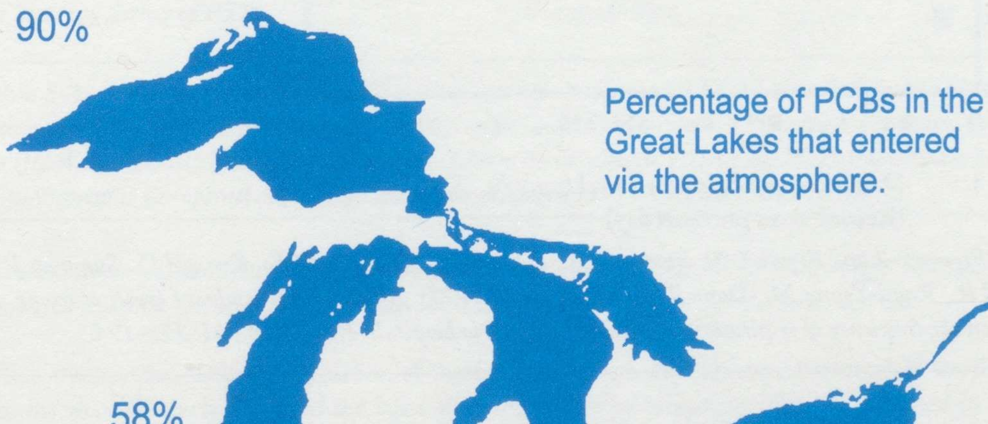

Figure 5-1. The Atmospheric Pathway
Strachan, W.M.J. and S.J. Eisenreich 1986. "Mass Balancing of Toxic Chemicals in the Great Lakes: The Role of Atmospheric Deposition." Workshop on Estimation of Atmospheric Loading of Toxic Chemicals to the Great Lakes Basin - October 1986. International Joint Commission.

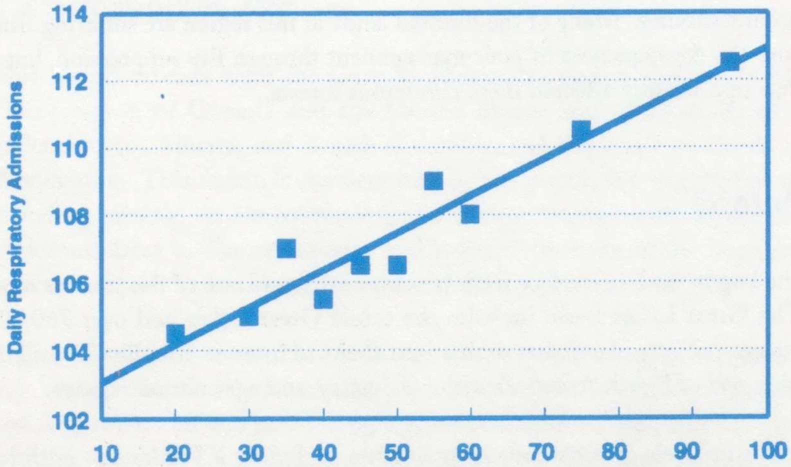

Figure 5-2. Daily Maximum One Hour Ozone Level (ppb)
(Recorded on previous day)

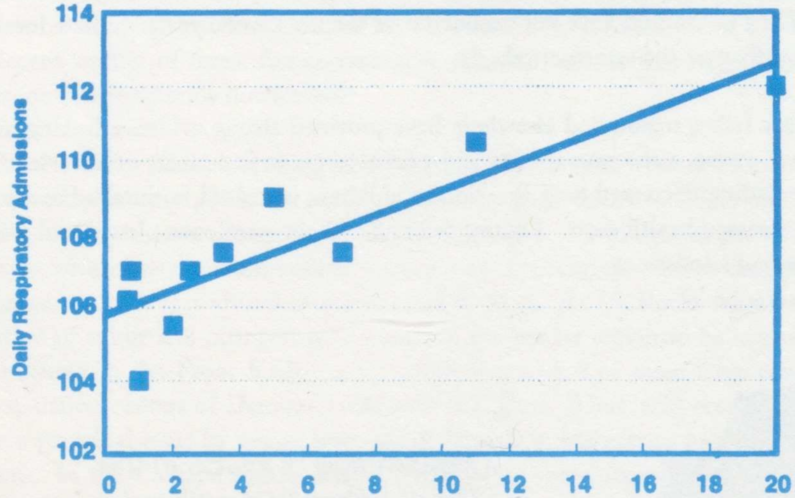

Figure 5-3. Daily Average Sulphate Level (μg/m³)
(Recorded on previous day)

(For both Figure 5-2 and Figure 5-3). Burnett R.T., Dales R.E., Raizenne M.E., Krewski D., Summers P.W., Roberts G.R., Raad-Young M., Dann T. and J.R. Brook, 1993: Effects of low ambient levels of ozone and sulphates on the frequency of respiratory admissions to Ontario hospitals. Envir. Res., 65: 172-194.

These findings demonstrate that adverse effects on respiratory and cardiac health are associated with relatively low air pollution levels, and that there does not appear to be a threshold level for ozone below which no adverse health effects are observed. Those at higher risk for adverse health effects from exposure to airborne contaminants include the very young, the elderly, smokers, and those with pre-existing cardiac conditions or respiratory diseases.

The levels of exposure of residents of the Great Lakes Basin to some PTSs have significantly decreased during the past 20 years. For example, the levels of DDT and its degradation products in the breast milk of Canadian women have decreased thirtyfold since 1967. Since the 1980s, the levels of lead in the blood of Ontario children have decreased over threefold, in parallel with the reduction in use of lead in gasoline.

Nevertheless, certain PTSs remain a concern in the Great Lakes Basin, including organochlorine pesticides, PCBs, dioxins, lead, and methyl mercury. Table 5-1 lists the PTSs currently covered under the 1997 Canada-U.S. Strategy for the Virtual Elimination of Persistent Toxic Substances.

LEVEL I	LEVEL II
Aldrin ^	Cadmium and its compounds
Dieldrin *^	1,4-Dichlorobenzene
Benzo(a)pyrene {B(a)P} *	3,3'-Dichlorobenzidine
Chlordane ^	Dinitropyrene
DDT, DDD, DDE *^	Endrin ^
Hexachlorobenzene (HCB) *^	Heptachlor and Heptachlor epoxide
Alkylated lead *	Hexachlorobutadiene
Mercury * and its compounds	Hexachloro-1,3-butadiene
Mirex *^	Hexachlorocyclohexane (including alpha, beta, delta, lindane)
Octachlorostyrene	4,4'-Methylenebis (2 Chloroaniline)
PCBs *^	Pentachlorobenzene
Dioxins (PCDD; 2,3,7,8-TCDD) *^	Pentachlorophenol
Furans (PCDF; 2,3,7,8-TCDF) *^	Tetrachlorobenzene (1,2,3,4- and 1,2,4,5-)
Toxaphene *^	Tributyl tin
	Polycyclic Aromatic Hydrocarbons (PAHs)^ as a group, including but not limited to:
	Anthracene
	Benzo(a)anthracene
	Benzo(g,h,i)perylene
	Perylene
	Phenanthrene

NOTE: Hexabromobiphenyl and Pentachlorophenol ***are listed as POPs on the CEC Council Resolution #95-5 but are not included on the Strategy listing of PTSs.***

Table 5-1. Level I and Level II Persistent Toxic Substances (PTSs) Identified in the Canada-U.S. Strategy for the Virtual Elimination of Persistent Toxic Substances. *The Critical Pollutants identified by the IJC Water Quality Board in 1985 are indicated with an asterisk (*) and the POPs from the Commission for Environmental Co-operation (CEC) Council Resolution #95-5 identified with a caret (^).*

Because these contaminants are persistent and frequently subjected to long-range transport, control measures must be implemented for both local sources and sources distant from the lakes.

When the first estimates of deposition of these contaminants were attempted in the late 1970s, concentrations were relatively high and the lakes were seen solely as receptors. This is illustrated by Figure 5-4, which shows the source regions for toxaphene deposited at Egbert, Ontario, in the northern portion of the Great Lakes Basin. Numbers shown in each state are estimated annual uses of toxaphene in tons per year, circa 1980. The use of toxaphene as a pesticide has since been largely discontinued in the United States.

More recently, with the reduction in concentrations of some PTSs in incoming air masses, the lakes are now becoming a source. One estimate of loadings of toxic chemicals to Lake Ontario made by Hoff et al. in 1996 (see Figure 5-5) shows volatilization of chemicals from the lakes to be an important factor. While one axis ("y") is described as "% of loading," the portion below the zero point represents a negative loading, that is, a release or volatilization of the contaminants into the atmosphere. If the depositional components of the flux (wet deposition, dry deposition, and gas absorption) are plotted as a

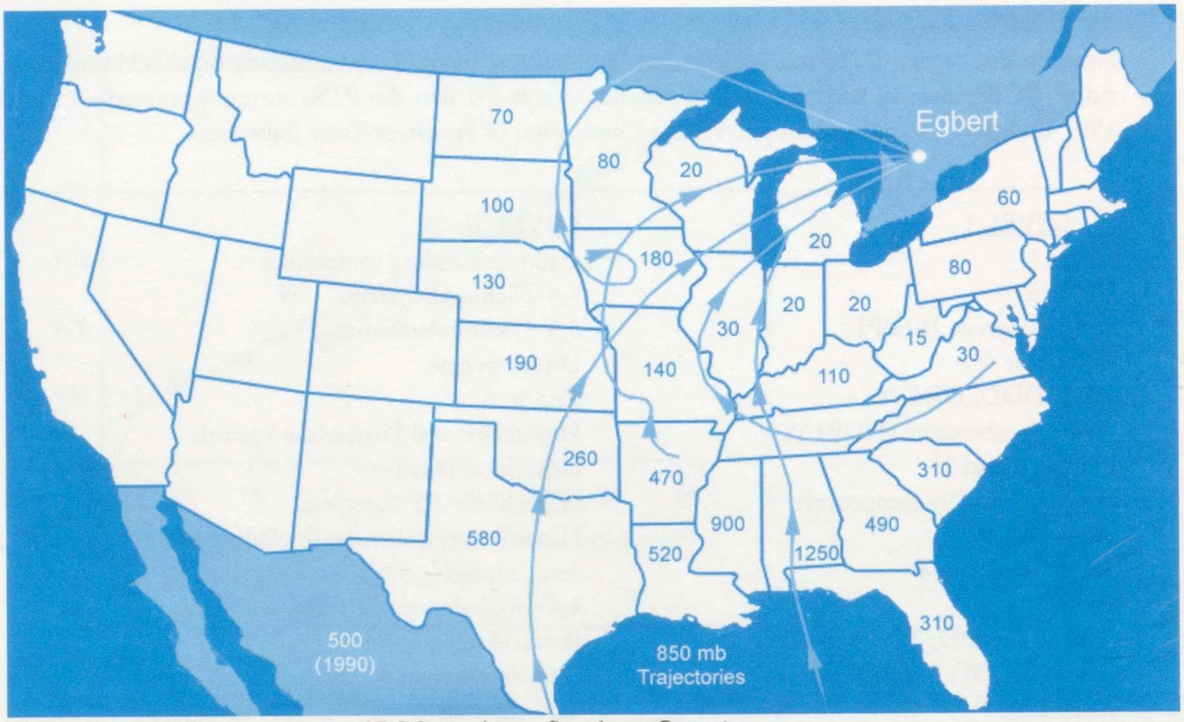

Figure 5-4. Measurement of PCCs in Air in Southern Ontario
Hoff et al., 1993. Chemosphere 27:2057-62.

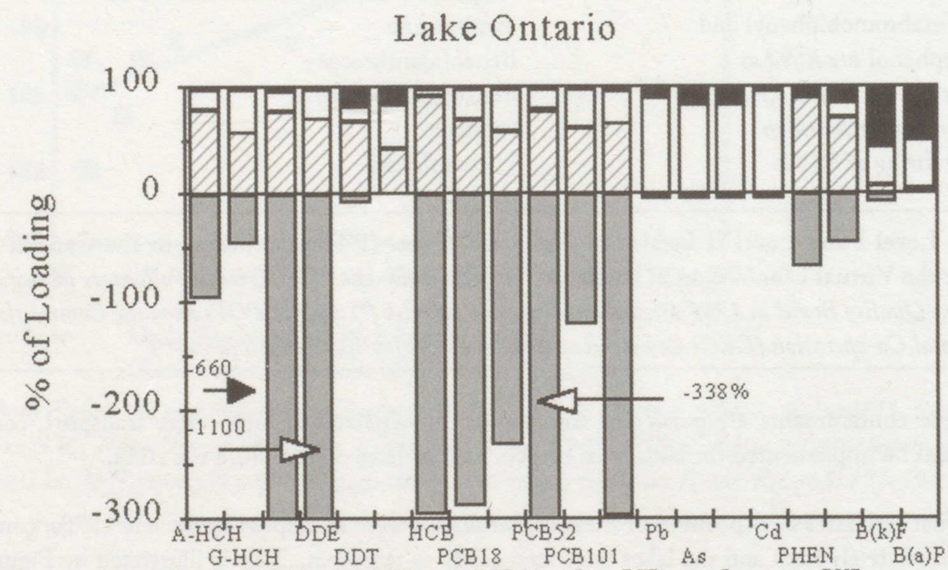

Figure 5-5. Mechanisms Involved in Transfer of Contaminants to and from Lake Ontario
Hoff et al., 1996. Atmos. Environ. 30: 3505-3527.

fraction of the total loading (represented by the area above the zero per cent line) for most of the organochlorine compounds, gas absorption is the most important process. When the volatilization of the chemical out of the water column is considered, however, it can be several times larger than all the combined atmospheric inputs.

For alpha- and gamma-hexachlorocyclohexane, Figure 5-5 shows that the concentration of these compounds in the atmosphere is in near equilibrium with Lake Ontario, with inputs nearly equal to the volatilization output. For the DDT-like species and PCBs, however, the lake is now a source to the atmosphere. For the metals and PAHs, the flux is still largely depositional (except for the lightest molecular weight PAHs, which have higher volatility). Recently these results have been interpreted to mean that the lakes are responding very quickly to the atmosphere's ability to carry off the chemicals above them. This is consistent with current understanding of the grasshopper and cold condensation effects, through which chemicals continue to migrate through the environment from warmer to colder climates. The Great Lakes are now a source of many chemicals to other regions of the globe.

As noted in Section 4, an air monitoring network around the Great Lakes, the Integrated Atmospheric Deposition Network, has one regional background station on each of the Great Lakes. The network provides good regional estimates of concentrations of several organic and inorganic chemicals. Recent information, developed as part of the ongoing Lake Michigan Mass Balance Study, has confirmed that Chicago is the source of large quantities of PCBs. A major portion of PCB transport from Chicago has been undetected by IADN monitoring, which has focused on measuring deposition in remote areas. This finding confirms the need for an additional emphasis on measuring sources and ambient concentrations in and around urban areas to obtain a better understanding of transport and deposition of air pollutants. In its current work under the Great Lakes Water Quality Agreement, the Board will continue to consider the extent to which routine monitoring capabilities need to be extended to include urban areas.

5.6 Eastern

The Eastern region of the Canada–United States border geographically covers the provinces of New Brunswick, Nova Scotia and Quebec, and the states of Maine, New Hampshire, and Vermont. The border in this region contains many shared resources, including the coastal water of the Gulf of Maine, the Saint Croix boundary river, and the watersheds of the St. Lawrence River and Lake Champlain.

The region is best characterized as diverse and vulnerable. The shared resources of the region include a diverse mixture of geological, hydrological, topographical, climatological, and biological features. This is matched by a diverse pattern of development, from the virtually undeveloped mountainous regions of the Laurentian Highlands and the Northern Appalachian Mountains to major urban centers like Montreal and New York City.

The region is quite vulnerable to air pollution because of its location downwind of the entire continent. Distant upwind decisions affect the environmental health of this region and its inhabitants. Efforts to control local sources of air pollution have been largely successful. Monitoring of pollutants such as carbon monoxide (CO), SO_2, and NO_2 has shown levels to be within the limits established by the respective federal governments.

Monitors on both sides of the border, however, are recording levels of ozone that exceed the human health standards in both countries. Ozone and its precursors are known to freely flow across the border, especially along the Atlantic coast. Attempts to quantify the levels of fine particulate matter along the border are under way, with monitoring plans for this pollutant under development in the United States. Previous studies documenting the levels of sulfate, a significant component of fine particulate matter, found evidence that high sulfate levels are causing visibility impairments and contributing to acidification of the region. Extrapolation of data from these studies suggests that areas within the region may experience levels of $PM_{2.5}$ above the standard recently adopted by the United States to protect human health.

Many unique resources exist within the Eastern region, and a full cataloguing of them is beyond the scope of this report. To further characterize the threat of air pollution, however, it is useful to examine air pollution and deposition in five smaller areas, or receptors, within the region — Kejimkujik in Nova Scotia, Acadia National Park in Maine, Casco Bay (one of the Great Waters in Maine), Hubbard Brook in New Hampshire, and Lake Champlain in Vermont, New York and Quebec (a transboundary lake that is also one of the Great Waters).

Kejimkujik

Kejimkujik, Nova Scotia, is the eastern-most acid deposition monitoring site in North America. Since the early 1980s, surface water chemistry has been monitored in this area to verify the ecological benefit from emissions control. Although concentrations of sulfate in rain have decreased in most of the Eastern region since the early 1990s, some locations such as Kejimkujik have statistically significant increasing trends in sulfate levels.

An extension of an earlier analysis of water quality trends in Nova Scotia, Newfoundland, Quebec, and Ontario yielded the following results: 51 per cent of 202 monitored sites showed decreasing sulfate; 1 per cent showed increasing sulfate; and 48 per cent showed no significant trend. A more recent regional analysis showed that 11 per cent of monitoring sites in these provinces continue to acidify; 33 per cent are recovering; and 56 per cent exhibit no statistical trend. The greatest difference between these results and those from the earlier analysis is that a substantial number of lakes in Nova Scotia and Newfoundland have shifted from the improving class to the class without an acidity trend.

Acadia National Park

Acadia National Park is an area of more than 19,000 hectares (47,000 acres) along the mid-coast of Maine that includes rich and diverse flora, birds, and mammal species. Downwind from large urban and industrial areas, it periodically experiences high concentrations of air pollutants. Ozone concentrations, for example, have violated federal standards and routinely exceeded standards set by the State of Maine.

Figure 5-6. Acadia National Park. Fraction of Sulfate Arriving at Acadia from Various Source Regions.
"Characteristics and Origins of Haze in the Continental United States." W.C. Malm, Earth-Science Reviews, 33(1992) 1-36, Elseview Science Pub.

Sulfates are the largest single contributor to visibility impairment. National Park Service studies have focused on the sulfur content of aerosols in extreme fog events, approximating the relative contributions of different source areas to aerosol concentrations at receptor sites. As shown in Figure 5-6, nickel smelting facilities in the area around Sudbury, Ontario, contribute the most sulfur to Acadia National Park (29 per cent). It is estimated that coal-fired power plants in the New York–Philadelphia area contribute approximately 15 per cent, while plants in northern New York contribute about 24 per cent. Midwestern SO_2 sources — primarily in Michigan — contribute about 9 per cent.

Casco Bay

Concern with atmospheric deposition to Casco Bay, Maine, focuses on PAHs, PCBs, nitrogen, phosphorus, sulfates, pesticides, and mercury and other trace metals. Recent sediment studies show elevated concentrations of cadmium, lead, mercury, PAHs, PCBs, silver, and zinc near population centers, in waste discharges, and in rural eastern Casco Bay, which is remote from known sources (Wade et al., 1995). A circulation model study of Casco Bay did not clearly indicate possible localized sources of these pollutants, suggesting atmospheric deposition as a significant source (Pearce et al., 1994).

Hubbard Brook, New Hampshire

Long-term data from the Hubbard Brook Experimental Forest in New Hampshire indicate that, although only small changes in stream acidity have been observed, large quantities of base cations have been lost from soils. These losses are apparently due to declines in base cation deposition, as well as leaching by acidic deposition. As a result, the response of soil and stream water chemistry to increases or decreases in acidic deposition might be substantially delayed. Because many factors beyond atmospheric deposition affect acidity trends, however, a more extensive study is required to more closely determine the role of deposition.

Lake Champlain

Lake Champlain is the sixth largest inland water body in the United States. Because the lake passes through the border and drains north into the St. Lawrence River, it is a receptor of transboundary importance. Air pollution threats to Lake Champlain manifest themselves as fish consumption advisories due to mercury and PCBs; increased levels of arsenic, PAHs, PCBs and lead in lake sediments; impairments of visibility; increases in regional ozone and fine particulate matter; and acid precipitation.

Monitoring/Modeling Issues

There is good coordination of ozone measurements in the immediate vicinity of the Maine–New Brunswick border. An international co-ordination effort exists to ensure that data from each network are of comparable quality and that an “airshed” approach is taken to data analysis. The region hosts a number of regional, national, and international sites that provide the basis for studies to document long-range transport of ozone, particulate matter, acidifying air pollution, and PTSs.

Regional atmospheric transport models have confirmed the long-range transport of ozone and its precursors, as well as particulate matter, acidifying air pollution and PTSs. There is an immediate need to develop mass balance models at specific receptor locations to begin to understand the contribution of PTSs from various pathways and sources to these locations. These mass balance models should allow the development of more effective management strategies.

Air Quality Strategies in the Eastern Region

The need for regional strategies to address air pollution in the Eastern region is well recognized and has led to the formation of several regional cooperative studies, regional air quality organizations, and regional air quality management strategies. For example, the Northeastern States for Co-ordinated Air Use Management (NESCAUM) is a thirty-year-old organization established by the governors of the six New England states, New York, and New Jersey. NESCAUM provides a forum to coordinate air quality management issues within the northeastern United States. NESCAUM has recently been working to interface with its counterparts in Eastern Canada.

The New England Governors and Eastern Premiers Association (NEG/EP) is a binational organization that provided leadership in developing a regional Acid Rain Control Plan well in advance of efforts by the federal governments. The NEG/EP recently passed two resolutions recognizing the threat of i) mercury pollution, and ii) acid deposition and calling for further controls.

The U.S. CAA also recognized the need for a regional solution to the ozone problems by designating a Northeast Ozone Transport Region (OTR) and establishing an OTR Commission (composed of official representatives from each of the 12 states in the region and the District of Columbia, plus the Administrators from the three northeastern EPA Regions). The Commission is charged with recommending to the federal government control measures for implementation throughout the region to reduce ozone levels below the federal standard.

A second U.S. effort to identify and coordinate abatement plans for ozone is the Ozone Transport Assessment Group (OTAG), which was established by the Environmental Council of States (ECOS) in 1995. OTAG comprises a 37-state geographic region in the eastern half of the country (plus the District of Columbia), and its work has been summarized by the Board in previous reports.

All of these efforts make it clear that the key to effective control and significantly improved air quality rests with continued and improved monitoring and the further development of binational approaches and strategies for emission reductions.

Recommendation

The Board recommends that any regional control strategies to limit transboundary air pollution be based on source transport and receptor regions as defined by the pollutant, meteorology and contributing sources.

6. HARMONIZATION AND STANDARD SETTING PROCESSES

6.1 Need for Collaboration on Criteria Documents

Currently, Canada and the United States have, and possibly will have into the future, different ambient air quality standards to protect the health of their citizens and environment. In the past, the Board has recommended adoption of identical standards as one approach to "harmonization" that could resolve some of the current difficulties in addressing transboundary air pollution. In 1992, the Commission concurred with this approach and recommended that "a common ozone standard for the reference region" be established for the Windsor–Detroit area.

Regardless of the specific standards in place, given the significance of transboundary transport, air quality management in both countries would benefit from a comprehensive binational policy to coordinate implementation, attainment, and maintenance of each country's standards in the border region.

Currently, each country has policies and mechanisms to address interstate and interprovincial transport of air pollution. The U.S. CAA Amendments of 1990 address these issues directly in sections 126 (interstate pollution abatement), 169B(c) (establishment of visibility transport regions and commissions), and 176A (interstate transport commissions). In Canada, interprovincial transport is addressed through processes established for the implementation of the Canadian Environmental Protection Act. In neither country, however, is there explicit recognition of the need to reflect on the quality of air masses imported or exported between the countries. Indeed, Section 179B of the CAA states that jurisdictions "are free to develop implementation plans for the attainment and maintenance of air quality standards in border regions as if there were no emissions present in the adjacent country."

Regardless of the specific standards in place, given the significance of transboundary transport, air quality management in both countries would benefit from a comprehensive binational policy to coordinate implementation, attainment, and maintenance of each country's standards in the border region.

In Section 1 of this report, the Board put forward an approach — Transboundary Air Pollution Transport Regions — to foster improved binational coordination in documenting and addressing significant reoccurring instances of transboundary air pollution. Approaches such as this should be focused, to a large degree, on ensuring that similar criteria or bases are used in developing national air quality standards (e.g. standards for tropospheric ozone). Under this approach, the Board recognizes that the two national processes and their outcomes are distinct. Violations of Canadian standards do not give rise to the same capacity for proscribed legal action that can follow exceedances of a standard in the United States. Also, certain economic factors, which must be considered in setting standards, may differ significantly in the two countries.

Even with these differences, it would be important to formally include scientists from one country in the preparation of and, more importantly, the process used to review scientific and health data contributing to the development of specific air quality standard in the other country. In the United States, this process is the development of the "criteria document"; there are similar, albeit less accessible processes in Canada.

Ideally, these scientists would be involved in analysis and discussion of atmospheric chemistry, meteorology, ecosystem impacts, and human epidemiology or clinical studies. Currently, many Canadians do participate in such discussions in the United States. The formalizing of a collaborative process, however, could result in documents that would be useful in the standard-setting processes in both countries.

The preparation of a Staff Paper under the standards development process by the U.S. EPA involves calculating the exposed population at different levels and considering other issues not directly addressed in the criteria document. The Staff Paper also recommends possible upper and lower limits for standards. Although a direct collaborative effort at this stage may not be warranted, Canada should consider the Staff Papers in-depth and place the points raised by the United States in a Canadian context when deriving its own standards.

While such steps would not assure the adoption of identical standards by both countries, the reasons for differences would be understood, and the existing scientific database for each pollutant would have been evaluated jointly.

Another important area of harmonization would be agreement on the technical aspects of preparing emissions inventories for both stationary and mobile sources. In Section 8, the Board has stressed the importance of ensuring that measurements of pollutants, particularly $PM_{2.5}$, on both sides of the border are compatible.

Recommendation

While the merit and possibility of harmonized standards continues to be considered by both governments, the Board recommends that, in addition to establishing the TAPTRs, the Commission advocate appropriate inclusion of experts from both countries in the development of air quality standards and criteria by each country, including joint involvement in elements (e.g. monitoring and emission inventory development) that contribute to such processes.

7. COLLABORATION WITH OTHER ORGANIZATIONS

Initiatives such as the Detroit/Windsor-Port Huron/Sarnia Air Quality Board Study, the British Columbia/Washington Environmental Cooperation Council, the Paso del Norte Region Study along the Rio Grande, and the Eastern North American Regional Ozone Study Area are examples of outreach activities that have led to greater involvement of the public in the issues of transboundary pollution in the United States and Canada.

Significant additional progress in addressing transboundary air pollution will require active involvement of a broader segment of the public in both countries. Efforts are needed to encourage the interest and participation of other groups, including public health agencies, nongovernmental organizations, and urban groups. In addition, communication within and among groups and agencies working on multiple issues, and cooperation between the IJC and such entities as the Commission for Environmental Cooperation (CEC) and the UN Economic Commission for Europe, should be encouraged and expanded.

7.1 Commission for Environmental Cooperation

In the years since its formation in 1994, the CEC has produced several reports that bear on the work of the Board and the Commission.

The CEC recently released *Continental Pollutant Pathways: An Agenda for Cooperation to Address Long-Range Transport of Air Pollution in North America*. This report built on the work of the IJC since 1985 and came to a number of conclusions similar to those developed by the Commission. In considering both PTSs and criteria pollutants, the CEC report affirmed the following:

Significant additional progress in addressing transboundary air pollution will require active involvement of a broader segment of the public in both countries. Efforts are needed to encourage the interest and participation of other goups, including public health agencies, nongovernmental organizations, and urban groups.

- Continental pollutants affect human health — especially in children, pregnant women, women of child-bearing age, the elderly, people with respiratory disease, and indigenous peoples and others who consume significant quantities of fish and game.
- Major sources of pollutants include electric utilities, the transportation sector, selected industries, municipal and medical waste incinerators, and agricultural chemicals.
- Improved emission reduction technologies and pollution prevention techniques and processes are available to reduce emissions of many of these pollutants.
- To enhance the capacity of the region as a whole to reduce the risks from continental pollutants, North American collaborative action should focus on a small number of important common source categories across the continent.

- North America should work with other regions to address emission sources from outside the continent.

- The three countries in North America should coordinate emissions inventories, ecological research, and monitoring.

The second CEC report of direct interest to the Board and Commission is *Long-Range Transport of Ground-Level Ozone and its Precursors: Assessment of Methods to Quantify Transboundary Transport within the Northeastern United States and Eastern Canada.* This report is the result of a binational collaborative project between NESCAUM and the Eastern Canada Transboundary Smog Issue Group (ECTSIG). The report gives an overview of the state of scientific knowledge on the generation and movement of ground-level ozone across the border between eastern Canada and the northeastern United States. The current ground-level ozone objective in Canada is 82 ppb averaged over one hour; the recently revised standard in the United States is 80 ppb averaged over eight hours.

The report noted that:

- Pollutants flow from the Midwestern United States and the Ohio Valley across southern Ontario, southern Quebec, and into the northeastern United States.

- Pollutants travel up the "northeast corridor" of the United States and flow into the Atlantic provinces of Canada.

- When locally generated pollution is factored in with long-range transport, ground-level ozone can be a regional problem over spatial scales of more than 600 km (373 miles) and time scales of several days.

The report also found that Canada and the United States have established a sound foundation upon which to measure airborne levels of smog and to model transport and associated mechanisms. It noted that a continuing coordinated scientific effort is needed to allow for more effective bilateral resolution of the transport problem.

In this report, the CEC recommended the following:

- Expand existing transport models to include the Canada–United States border as well as regions on each side of the border.

- Reverse the current trend of closing monitoring stations within both countries. Monitoring stations are critical for tracking the benefits of emission reduction programs and compliance with air quality standards.

- Increase comparability of air quality data used to evaluate transboundary transport and create a database to store all ambient monitoring data for the study area.

- Develop additional analyses to track winds and emissions in the Windsor–Quebec Corridor and the Southern Atlantic Region of Canada, along with the U.S. northeast, northwest and midwestern regions.

The report also highlights the need for a long-term, regional-scale air management approach to reduce or eliminate transboundary transport of ground-level ozone. This need is consistent with the recent recommendations of the 37 U.S. states and the District of Columbia under the OTAG to address the transport of regional smog in the eastern United States, as well as several Board recommendations in this and previous reports.

The third CEC report of interest is *Taking Stock: North American Pollutant Releases and Transfers.*

This report analyzed 1994 data on releases and transfers from industrial facilities based on the pollutant release and transfer register (PRTR) in each country. It considered the National Pollutant Release Inventory (NPRI) in Canada, the Toxic Release Inventory (TRI) in the United States, and the Registro de Emisiones y Transferencia de Contaminantes (RETC) in Mexico. In the case of Mexico, available information was very limited. However, 11 of 51 U.S. company reports reviewed by the CEC did include some aggregated data on their Mexican facilities and 5 reports described corporate environmental activities in Mexico.

The CEC report indicates that air emissions tend to be greater in the Great Lakes, Western, and Plains regions. Overall, air emissions represented 48 per cent of the total releases and transfers. The exception is the Eastern region, where Canadian NPRI facilities report largely surface water discharges and U.S. TRI facilities report almost exclusively air emissions.

In 1994, on-site releases and off-site transfers of chemicals to treatment and disposal facilities were reported from every state and province. Total releases and transfers of chemicals by industries amounted to 1.5 billion kilograms (3.3 billion pounds). U.S. facilities accounted for 85 per cent of this total. Individual Canadian facilities, however, released on average 2.5 times more pollutants than those reported by the average U.S. facility, and the average chemical transfer in Canada was approximately double that in the United States.

The pollutants considered are a mix of PTSs, carcinogenic contaminants, criteria and conventional pollutants, and others contained in individual permits. Certain permitted activities, such as disposal or treatment by underground or deep well injection, are also considered to be releases, and can be a large contributor to the total releases in some areas.

The CEC report presents and analyzes a wealth of data that should be carefully considered when attempting to rank regions by chemicals released.

7.2 United Nations Economic Commission for Europe

In February 1998, the UNECE released drafts of two protocols on Long-Range Transboundary Air Pollution that deal with heavy metals and with persistent organic pollutants. On 24 June 1998, at the fourth "Environment for Europe" Ministerial Conference in Aarhus, Denmark, the Parties to the UN/ECE Convention on Long-Range Transboundary Air Pollution adopted the protocols to the Convention.

The following countries have signed the two protocols: Austria, Belgium, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Republic of Moldova, Romania, Slovakia, Slovenia, Sweden, Switzerland, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States of America, and the European Community. The former Yugoslav Republic of Macedonia submitted a Declaration in lieu of signing.

The protocol on heavy metals targets three particularly harmful substances: lead, cadmium, and mercury. Under the protocol, countries are to reduce emissions of these three metals below their 1990 levels (or an alternative year between 1985 and 1995), principally from industrial sources, combustion processes, and waste incineration. This protocol specifies best available technology (BAT) to control emissions from 11 sectors, including fossil fuel-fired utilities, the iron and steel industry, the nonferrous metals industry, and the cement industry. It also requires participating countries to phase out leaded gasoline (if they have not already done so), and may require national measures to lower heavy metal emissions from other products, such as mercury in batteries.

The protocol on POPs sets stringent limits for dioxin and furan emissions from stationary sources, and lists the best available technology to control emissions from waste incineration and the metallurgical industry, including iron and steel, copper, and aluminum production. It also lists specific control techniques to reduce PAH emissions from coke production (iron and steel), anode production (aluminum), and diesel-powered mobile sources. Further, the POPs protocol bans the production and use of some products outright (aldrin, chlorodane, chlorodecone, dieldrin, endrin, hexabromobiphenyl, mirex, and toxaphene), while severely restricting the use of DDT, HCH (including lindane) and PCBs (which are scheduled for elimination at a later stage). It also includes provisions for dealing with the wastes of banned products, and obliges countries to reduce their emissions of dioxins, furans, PAHs, and HCB below 1990 levels.

In addition, each protocol contains a commitment to research and development and to monitoring, calling for cooperation on emissions inventories, measuring long-range transport and deposition levels, and modeling to determine pollutant pathways. Information on heavy metal content of certain products is also to be tracked.

The two protocols may set a framework for legislation to address these pollutants in countries in Europe and North America. The Board will continue to review the protocols to determine opportunities to implement the protocol measures in a North American setting. In addition, the Board will attempt to identify a European contact or contacts for ongoing collaboration and information exchange between the two regions.

In a related activity, under the auspices of the United Nations Environmental Program (UNEP), officials from 92 countries met on July 3 in Montreal, Canada, in first-round talks on the minimization and eventual elimination of POPs such as DDT and PCBs.

Twelve POPs are on the UNEP list: DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, hexachlorobenzene, mirex, toxaphene, polychlorinated biphenyls, dioxins and furans. This closely parallels the Criteria Pollutants list developed by the IJC's Water Quality Board for the International Joint Commission in 1985 and discussed in the Great Lakes portion of Section 5 of this report, as well as that considered by the UNECE (Table 7-1).

The Montreal meeting was the first step toward adopting a POPs treaty in the year 2000; at its conclusion, the UNEP secretariat was mandated to prepare a draft outline of the substantive elements of such a convention. This outline would be used in the drafting of the specific text for any agreement.

The meeting also struck an expert group to develop science-based criteria and procedures for identifying additional POPs for future consideration. Agreement was also reached on the need to provide for technical cooperation and financial assistance to allow the participation of developing nations. The next formal meetings are scheduled for February 8 to 12, 1999.

PESTICIDES	INDUSTRIAL CHEMICALS
aldrin * chlorodane * chlorodecone DDT * dieldrin * endrin heptachlor hexachlorobenzene (HCB) * mirex * toxaphene * hexachlorocyclohexane (HCH) (including lindane)	hexabromobiphenyl polychlorinated biphenyls (PCBs) * **BI-PRODUCTS OR CONTAMINANTS** dioxins * furans * polycyclic aromatic hydrocarbons (PAHs)*

(*) indicates Critical Pollutants determined by IJC Water Quality Board 1985

Table 7-1. UN/ECE Persistent Organic Pollutants in Draft Protocol, January 1998

Recommendation

The Board recommends that the Commission maintain a dialogue with the CEC and consider opportunities for interaction with the UNECE to ensure that their work reflects North American practices and to consider which European approaches to determining and managing air quality might be applicable in North America.

8. SURVEILLANCE ISSUES

8.1 Eastern $PM_{2.5}$ Quantification

The promulgation of the U.S. EPA standard for fine particulates ($PM_{2.5}$) included a requirement for ambient sampling of $PM_{2.5}$ at 1,500 sites distributed throughout the United States. The criteria for siting monitors will include high population density, since one of the U.S. EPA's objectives is to determine the locations that do not meet the daily or annual $PM_{2.5}$ standards. Such sites would frequently be large urban centers.

Given this criterion, the Board could determine whether or not sufficient population-based or urban monitors are placed in the border regions. It could also ascertain if there is an adequate number of $PM_{2.5}$ transport monitoring sites in or adjacent to the border regions to allow determination of the seasonal and temporal concentration patterns of $PM_{2.5}$. This would allow the Board and the Commission to identify the temporal trends in $PM_{2.5}$ concentrations and assess the implications of the measured levels for future control strategies.

The promulgation of the U.S. EPA standard for fine particulates (PM_{25}) included a requirement for ambient sampling of PM_{25} at 1,500 sites distributed throughout the United States. The criteria for siting monitors will include high population density, since one of the U.S. EPA's objectives is to determine the locations that do not meet the daily or annual PM_{25} standards. Such sites would frequently be large urban centers.

Achieving a coherent understanding of $PM_{2.5}$ releases and transport is essential to establishing the most appropriate strategies to reduce daily and annual average concentrations. In this particular instance, however, since $PM_{2.5}$ is a physical–chemical mixture of ultra-fine and fine particles and inorganic and organic chemicals, surveillance must go beyond simple mass measurements. Thus, the Commission should review the information acquired by the major $PM_{2.5}$ research programs implemented by the United States over the next three to five years to determine the specific chemicals of concern, the particle size of concern for human health, and the sources requiring control. Obviously, because it is not limited to a single pollutant and a single type of risk, this undertaking will require consideration of a vast amount of data and information.

Furthermore, this assessment must be done in concert with current programs examining the control options for tropospheric ozone, since some $PM_{2.5}$ is formed as a consequence of photochemical processes that produce ozone. $PM_{2.5}$ can exist in the atmosphere concurrently with gases such as ozone, SO_2, and NO_2.

8.2 Focus on Endpoints (Biota/Human Impacts)

Monitoring air quality and deposition in the border region is not enough. The status and trends in sensitive receptors of air pollution must also be periodically monitored. Certain receptors are particularly vulnerable to certain pollutants, including:

- fish, wildlife, and human health to PTSs;
- asthmatics, children, the elderly, vegetation (including crops) to ozone;
- human health and visibility to PM; and
- lakes, streams, soils, vegetation, estuaries, and aquatic biota to deposition (wet and dry) of sulfates and nitrates.

Both the United States and Canada have programs to assess these important endpoints through human epidemiological and ecosystem studies, such as the U.S. Environmental Monitoring and Assessment Program (EMAP) and the Canadian Ecological Monitoring and Assessment Network (EMAN). Presently, there is considerable interest in charting the recovery of fresh waters in the eastern region of North America in response to decreases in sulfate deposition. Lack of sustained funding and shifting priorities, however, currently make it difficult for agencies to maintain long-term monitoring and assessment studies of human health and ecosystems.

8.3 Emissions Trading and Environmental Integrity

Programs that rely upon free-market principles for air pollution abatement strategies are increasingly being offered as an alternative to traditional command-and-control programs. The first large-scale implementation of such a program was under Title IV of the U.S. CAA, a program designed to respond to the environmental damage caused by acidifying emissions. Title IV focused primarily on reducing sulfur-bearing emissions from utilities and other sources. The success or failure of this program depends on the perspective from which it is viewed. As a program to produce the least-cost reductions of SO_2 emissions, it has been judged highly successful: SO_2 allowance costs fell from a projected $330 U.S. per tonne ($300 per ton) to an actual cost on the order of $83 U.S. per tonne ($75 per ton). As a program aimed at solving an environmental concern, however, the outcome is less clear: acidifying emissions remain a concern, and further reductions are needed.

Under a cap-and-trade program, benefits are often presented in terms of total tons of emission reductions, a value that can easily be calculated. When trading is turned over to the free market, however, there is no environmental integrity test that considers geographic or other factors important in determining the total environmental impact of the emission reductions. Under a cap-and-trade program, overall emissions may be reduced, but emissions that adversely affect critical or sensitive areas may actually increase and damage in such areas may be exacerbated.

Because market instruments are increasingly considered a primary strategy for abating other air pollution problems, the absence of an environmental integrity test becomes more critical. For example, an emissions trading program is being considered for the ozone precursor pollutant, NO_X. In the atmospheric chemical process by which ozone precursors are transformed into the offending pollutant, three factors — time, distance, and season — are critical to determining the actual reduction of ozone. It may be that emissions trading should be limited in distance or that a "discount rate" should be established in order for the program to provide meaningful environmental benefits along with overall net emission reductions.

Recommendations

In conjunction with efforts to assess the release and transport of $PM_{2.5}$, the Commission should ensure that any monitoring network established by the United States over the next five years is at least compatible with, or can be compared to, $PM_{2.5}$ monitoring done in Canada.

This does not necessarily mean that both countries need identical monitoring equipment. There should, however, be a program to encourage collocation of monitoring equipment so that collected data can be used to determine flux and distribution of $PM_{2.5}$ throughout the entire transboundary region. This program should be consistent with the seamless border approach for the airshed shared by the United States and Canada.

The Commission should urge governments to determine appropriate endpoints and indicators of air quality (such as hospital admissions and alterations in fisheries) and to conduct periodic surveys of air pollution receptors (such as sensitive vegetative species) to determine the effects of cleaner air in the border region. This indicator monitoring should include a research component to ensure that all the significant health and ecosystem linkages (e.g. air quality effects on forests) are determined and understood.

9. EMERGING AND ANTICIPATORY ISSUES

9.1 Coal-Fired Power Plants

Throughout this report, the Board has identified the major environmental and human health threats from air pollution in the boundary region. These threats vary from region to region. The emissions of concern, however, have several common sources, the major contributors being fossil fuel power plants, transportation, and industrial processes. For some of these sources, much is known, and policies that will achieve significant reductions in emissions need to be implemented. This will involve putting in place comprehensive emission controls in both countries.

Concerns about power plants can be broken into two categories: new facilities and currently operating facilities. As the electricity grid in both countries becomes more integrated (as seen by the increase in Canadian exports of electrical energy to the United States shown in Figure 9-1), emission reductions must take place in both countries. Air emissions from new facilities can be well controlled, and emissions control technology can readily be designed into the construction of such facilities. Both countries have New Source Review (NSR) programs to ensure that new facilities are fitted with the best available control technology. With proper maintenance and operation, the emissions from a new facility are a small fraction of those from an uncontrolled plant. Because of this environmental advantage, it will be important for new facilities to assume more of the total energy generating capacity.

It is these existing facilities with relatively high emissions, which contribute to the elevated concentrations of $PM_{2.5}$, ozone, acidifying air pollution, and PTSs. To successfully abate the formation of [these pollutants] comprehensive controls on these facilities are essential.

For existing power plants, the story is much different. A significant portion of these plants which generate electricity through the combustion of coal has generally been exempt from comprehensive control requirements. Early efforts to control emissions led to the placement of limited technology in some of these facilities; some constructed stacks to allow the pollution to be more widely dispersed. It is these existing facilities with relatively high emissions, which contribute to the elevated concentrations of $PM_{2.5}$, ozone, acidifying air pollution, and PTSs. To successfully abate the formation of $PM_{2.5}$ and ozone, and emissions of acidifying pollutants and PTSs, comprehensive controls on these facilities are essential. Controls could be

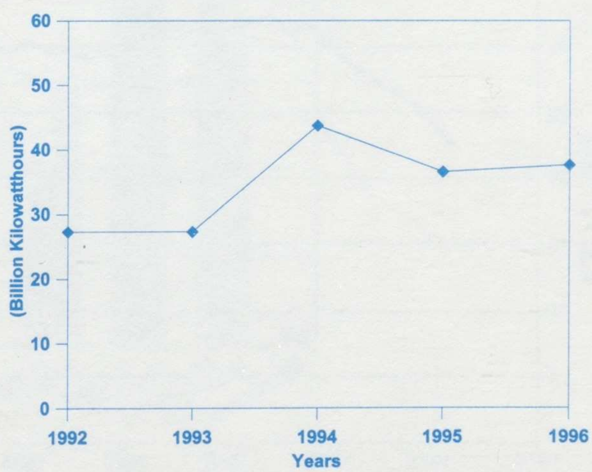

Figure 9-1. U.S. Electricity Imports/Canadian Exports
Graph prepared by IJC from data in Electric Power Annual 1996, Volume II, U.S. Department of Energy.

achieved through the establishment of an "Old Source Review" program, similar to the NSR programs for new facilities.

Significant new information has recently become available regarding emissions of hazardous substances from the electrical generation (particularly coal-fired utilities) sector.

The U.S. EPA recently issued two studies, the *Mercury Report to Congress* and a *Study of Hazardous Pollutants from Electrical Utilities*. These two reports confirmed that the electrical generation (coal-fired) source sector is a factor in the continued release of PTSs (particularly mercury) into the environment. The Board plans to continue assessing these and other documents to determine appropriate emission reduction objectives and strategies for this segment of the electrical generation sector.

9.2 Mobile Sources

9.2.1 Energy Conservation

For a variety of reasons, including the recent outcome of climate change negotiations in Kyoto, Japan, governments will need to support sound energy policies that can concurrently reduce emissions of NO_X and other pollutants. Such policies could include incorporating the true total cost of energy into consumer energy prices and increasing the U.S. Corporate Average Fuel Economy (CAFE) standards for automobiles. Raising current CAFE standards could present a powerful opportunity to address a variety of air pollution problems, including NO_X emissions. Since the mid-1970s and early 1980s, no progress has been made in increasing the fuel efficiency of motor vehicles (see Figure 9-2). In fact, the introduction of heavier and less fuel-efficient "sport utility vehicles" has reversed any gains made prior to that time. This situation is compounded by the fact that there are now more vehicles traveling greater distances every year.

These current vehicle trends indicate a need to develop increasingly fuel-efficient vehicles and to promote policies that encourage the purchase and use of low-emission and zero-emission vehicles (LEVs and

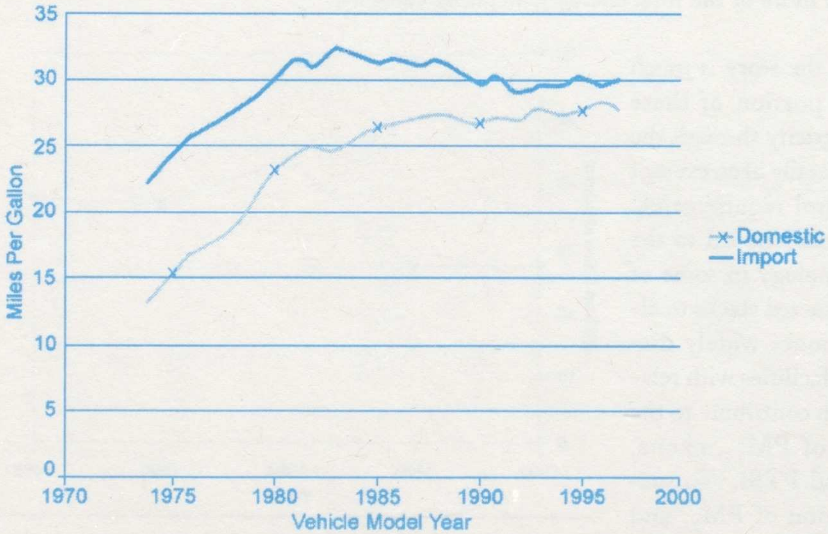

Figure 9-2. New Car Corporate Average Fuel Economy by Model Year.
American Automobile Manufacturers Association, Facts 7 Figures, 1997

ZEVs). Currently, the major automobile manufacturers have indicated that LEVs will be available at a reasonable cost in the next few years. While inclusion of such vehicles in the traffic mix has air quality benefits, it will take many years before LEVs and ZEVs will be the dominant segment of the U.S. and Canadian passenger car fleet. At the same time, major investments must be made in mass transit systems to promote their use and to reduce reliance on motor vehicles. All these measures have the potential to concurrently reduce energy use and reduce total emissions of NO_x from the motor vehicle sector.

9.2.2 Sulfur in Gasoline

High sulfur content in gasoline is a concern in both the United States and Canada, particularly in regions where the resultant SO_2 from auto emissions worsen air quality. As shown in Figure 9-3, gasoline outside of the state of California contains about 400 ppm of sulfur. Gasoline with the highest sulfur content (553 ppm) is used in southern Ontario, worsening the already compromised air quality in that area. Toronto's gasoline sulfur emissions are the highest in Canada.

The Canadian refining industry, built to process light sweet crude oil, has invested significant funds over the past decade in technology to process sour or high sulfur crude from Western Canadian heavy oil and tar sands sources. It is estimated that meeting the California gasoline standard of 30 ppm sulfur by these refineries would require an investment of $1.78 billion or an increase in the cost of gasoline of 1 cent per litre (3.78 cents per gallon).

In addition to the direct reduction in sulfur dioxide emissions that would be realized in both countries from all vehicles using lower sulfur fuel, more importantly, auto manufacturers are promoting the production of such fuel as crucial to the effectiveness of emission controls on current cars and future LEVs.

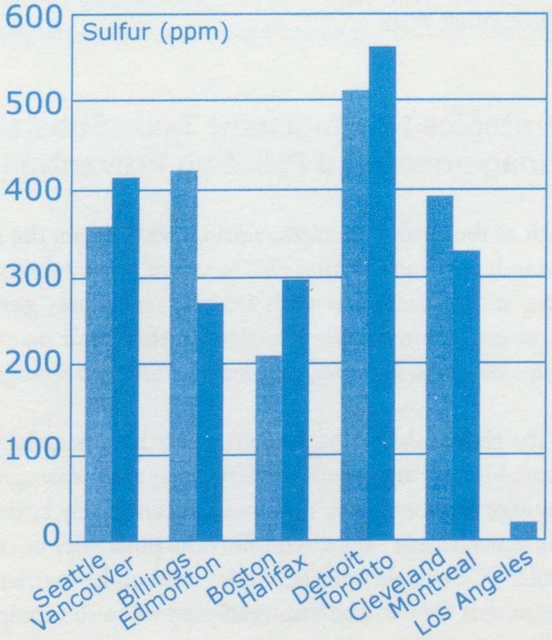

Figure 9-3. Sulfur Content of Unleaded Gasoline, Summer of 1995
Initiative on the Potential Impact of Sulfur in Gasoline on Motor Vehicle Pollution Control and Monitoring Technologies, Southam Newspapers, March 2, 1998

Within two years, Honda, Toyota, and General Motors will have the capacity to sell "virtually no emissions" vehicles (Z-LEVs). The exhaust gases from Z-LEVs will be nearly free of CO and NO_X, and emit only 0.002 grams of non-methane organic gases per kilometre (0.00014 ounces per mile), a level 94 per cent below the voluntary higher standard agreed to by most major auto makers. Because high sulfur levels in gasoline will interfere with the proper operation of these systems, however, the full benefit of cleaner auto emissions will be realized only if the sulfur content is reduced significantly on a national basis in both countries.

9.2.3 Diesel Particulates, $PM_{2.5}$ Precursors, and Co-Pollutants

After it was demonstrated that PM_{10} levels are associated with a variety of adverse health effects, data were assembled and reviewed by the U.S. EPA that suggested that the particles less than 2.5 microns in diameter ($PM_{2.5}$) were the most significant contributors to adverse health effects. In some urban regions, such as London, England, where more than 17,000 taxis are driven by small diesel engines along throughways with a high proportion of heavy diesel traffic, diesel particles may be the predominant species within the $PM_{2.5}$ fraction. In Holland, it has been shown that people who reside adjacent to motorways have higher exposures to such particles, and that the risk of lower respiratory infections or depressed lung function in children is thereby increased. There is also experimental and epidemiological evidence that increased exposure to diesel emissions increases the risk of lung cancer. It is not known, however, precisely what component of such particles increases their toxicity or carcinogenicity.

It may therefore be anticipated that considerable effort in the future will be devoted to developing measures that might reduce diesel emissions. One obstacle to this is that although new diesel engines do not emit high levels of particles, they emit increasingly higher levels as they get older. Alternative engines, such as those using natural gas or new fuel-cell technology, offer solutions that would greatly reduce or eliminate particle emissions. The issue of diesel emissions will be a major item on the urban transportation agenda in the coming years.

9.3 Reduction Strategies for Persistent Toxic Substances: Life Cycle Management and Pollution Prevention

For some known PTSs, such as the pesticides mirex, aldrin, and dieldrin, the most appropriate emission reduction strategy has been to ban the production and/or use of these substances. Consistent with this approach, the United States and Canada have each enacted regulations governing the registration of new chemicals that require an evaluation of their persistence before their manufacture and/or sale is permitted. There are two groups of PTSs, however, that require different management approaches.

The first group comprises the chemicals and heavy metals that have beneficial or necessary uses. Until effective substitutes of reasonable cost are found, countries may need management strategies that allow selected uses of these substances while ensuring that they are completely retrieved after use for recycling or disposal. This "life cycle management" approach offers the possibility of controlling substances from cradle to grave. For example, PCBs could continue to be used under restricted conditions in electrical equipment, with the intention that they will be fully recovered when the equipment has reached the end of its life and is ready for disposal.

Mercury-containing products such as fluorescent light bulbs also offer an opportunity for life cycle management. Since their use is encouraged in energy conservation programs, there is no overwhelming incentive to ban them and eliminate an environmental benefit. Given the potential risks of uncontrolled disposal of these products in landfills, however, programs must be in place to ensure that they are collected and properly recycled at the end of their life.

The second group of PTSs that may require special management strategies comprises substances that are products of incomplete combustion and trace contaminants that are formed unintentionally in industrial processes. These substances include dioxins, furans, PAHs, and a myriad of polycyclic organics containing oxygen and/or nitrogen in their complex structure. These compounds, even when produced in trace amounts, are extremely difficult and costly to remove or recover from the process. Because their persistence and accumulation in the environment are of great concern, pollution prevention may be the soundest strategy available to deal with them. Under pollution prevention, new or modified technologies to avoid or prevent the formation of these products of incomplete combustion and/or trace contaminants are developed.

Incentives must be provided to encourage industry to actively research and develop pollution prevention technologies for these PTSs. Public–private partnerships should be considered when the industry does not have the full capacity to do pollution prevention research and development on its own. The Great Lakes region, for example, has been very active in pursuing pollution prevention initiatives. Some of these are discussed further in a recent IJC report entitled *1995/97 Priorities and Progress under the Great Lakes Water Quality Agreement* as well as on the U.S. EPA Great Lakes National Program Office website (www.epa.gov/glnpo/p2).

Recommendation

The Board has recommended to the Commission the development of a uniform standard throughout both countries for sulfur content in gasoline of 30 ppm annual average, with a maximum level of 80 ppm, optimally by the year 2001 but certainly no later than 2005. Subsequently, the Commission made largely the same recommendation to the governments of the United States and Canada.

10. THE WAY AHEAD: FUTURE BOARD ACTIVITY

In its report to governments, "The IJC and the 21st Century," the Commission identified transboundary air quality as one of the specific challenges for the next several decades. It also highlighted the importance of continually assessing the existing and long-term situation with respect to transboundary air flows and their effects, tracking future changes in air quality, and formulating appropriate remedial and preventative measures. To assist it in providing advice to the governments, the Commission has requested the Board to undertake studies of:

i) the transboundary flows and deposition of persistent toxic chemicals, together with an examination of existing control programs and any proposed changes to those programs, as well as an assessment of the adequacy and consistency of efforts in both countries to prevent transboundary damage;

ii) the transboundary flows and the interactions among toxic substances, particulate matter, ozone and climate, and their effects on ecosystem and human health;

iii) the transboundary flows of those airborne nitrogen species which exacerbate eutrophication damage to lakes, estuaries and coastal waters and also contribute to ozone formation and acid deposition; and

iv) the trends in transboundary flows, and an assessment of the effectiveness of current monitoring and surveillance programs to detect such trends and identify causal factors.

The future work of the Board, into the twenty-first century, will be rooted in the above studies, which are largely consistent with the current activities of the Board.

In its report to governments, "The IJC and the 21st Century," the Commission identified transboundary air quality as one of the specific challenges for the next several decades.

During 1995–97, the Board reviewed the status of research on the physical and chemical properties of the 29 contaminants and families of contaminants (see Table 5-1 in Section 5) in the U.S.–Canada Binational Toxics Strategy, as well as associated emission inventories, modeling efforts, and deposition and ambient air monitoring. The initial output of this review was tabled at a May 1997 workshop co-sponsored with the Commission's Great Lakes Water Quality Board and held in Romulus, Michigan. The workshop also considered the Lake Michigan Mass Balance Study and ongoing specific efforts in pollution prevention. A summary of the workshop is contained in the Commission's report, *1995/97 Priorities and Progress under the Great Lakes Water Quality Agreement.*

As part of the Commission's 1997–99 Great Lakes Priorities, the Board is continuing its efforts to characterize the long-range transport of PTSs to the Great Lakes Basin. The Board is currently working to determine the status of several research needs identified during the Romulus workshop, including the need to further link specific PTSs found in the Great Lakes Basin to their originating sources and source regions. The ultimate objective of this work is to map these source–receptor relationships.

Concerning other pollutants and pollutant sources, the Board will begin to review and comment on the evolution of new Canadian ambient air guidelines for $PM_{2.5}$, and will continue to review the implementation of the recently promulgated U.S. standard for this pollutant. Under this review, the Board will consider the adequacy of $PM_{2.5}$ monitoring, particularly in the transboundary region, and the comparability of data generated by the two distinct measurement technologies chosen by the United States and Canada. The Board will also examine the measurement and transboundary movement of the ozone and acid rain and ozone precursor NO_X, as well as continue to assess the effects of these pollutants on visibility, biota, and human health.

Concerning sources of emissions, the Board will focus on emissions of acid gases (particularly NO_X) and particulates from electrical utilities and the mobile source sector. It will also give further attention to the utility sector as a source of mercury.

The Board will continue to review activities along the entire length of the transboundary region, and intends to report on significant developments as they emerge. Activities of the Board can be further tracked through the Commission's website, "www.ijc.org".

Acronyms

ADOM	Acid Deposition Oxidants Model (Canadian Eulerian model)
AOI(s)	Area(s) of Influence
AOV(s)	Area(s) of Violation
BAT	best available technology
CAFÉ	Corporate Average Fuel Economy
CAPMoN	Canadian Air and Precipitation Monitoring Network
CASAC	Clean Air Act Science Advisory Committee
CEC	Commission for Environmental Cooperation
CFC(s)	chlorofluorocarbon(s)
CO_2	carbon dioxide
DDT	dichlorodiphenyltrichloroethane
ECOS	Environmental Council of States
ECTSIG	Eastern Canada Transboundary Smog Issue Group
EMAN	Ecological Monitoring and Assessment Network (Canada)
EMAP	Environmental Monitoring and Assessment Program (U.S.)
EMEFS	Eulerian Model Evaluation Field Study
EMEP	European Monitoring of the Environment Program
ERP	External Review Panel
FERC	Federal Energy Regulatory Commission
G.V.R.D.	Greater Vancouver Regional District
HCB	hexachlorobenzene
IADN	Integrated Atmospheric Deposition Network
IAQAB	International Air Quality Advisory Board
IJC	International Joint Commission
IMPROVE	Interagency Monitoring of Protected Visual Environments
LEVs	low-emission vehicles
LRTAP	Long-Range Transboundary Air Pollution
NADP	National Atmospheric Deposition Program
NARSTO	North American Research Strategy on Tropospheric Ozone
NEG/EP	New England Governors and Eastern Premiers Association
NESCAUM	Northeastern States for Co-ordinated Air Use Management
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NPRI	National Pollutant Release Inventory
NSMP	National Smog Management Plan
NSR	New Source Review
O_3	ozone
OTAG	Ozone Transport Assessment Group
OTR	Ozone Transport Region
PAH(s)	polycyclic aromatic hydrocarbon(s)
PCB(s)	polychlorinated biphenyl(s)
PICs	products of incomplete combustion
PCDDs	polychlorinated dibenzo-p-dioxin
PCDFs	polychlorinated dibenzo furans
PM_{10}	particulate matter (<10 microns)
$PM_{2.5}$	fine particulate matter (<2.5 microns)
POP(s)	persistent organic pollutant(s)
PRTR	Pollutant Release and Transfer Register
PTS(s)	persistent toxic substance(s)
RADM	Regional Acid Deposition Model (U.S. Eulerian model)
RAMPs	Regional Air Management Partnerships
RETC	Registro de Emisiones y Transferencia de Contaminantes (Mexico)
RIPs	Regionally Integrated Plans
ROSA	Regional Ozone Study Area
RSMPs	Regional Smog Management Plans
SIPs	state implementation plans
SO_2	sulfur dioxide
SO_x	sulfur oxides
SOMA	Sulfur Oxides Management Area
TAPTR(s)	Transboundary Air Pollution Transport Region(s)
TRI	Toxic Release Inventory
TSP	total suspended particles [particulates?]
UNECE	United Nations Economic Commission for Europe
ZEVs	zero-emission vehicles

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